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STORM HAZARDS '79 - F-106B OPERATIONS SUMMARY

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SUMMARY

The National Aeronautics and Space Administration is undertaking a storm hazards research program to extend the knowledge and understanding of atmospheric processes as they affect aircraft design and operations. In the current phase, the Storm Hazards '79 program, preliminary flight tests with an NASA-owned F-106B aircraft were made on the periphery of isolated thundercells located within 100 n.mi. of the NASA-Langley Research Center using NASA-Wallops Flight Center weather radar support.

In addition to research in the correlation of different storm hazards, two other experiments were conducted. Provision was made for airborne measurements of the lightning-generated electromagnetic environment by a direct-strike lightning measurement system. In addition, a few atmospheric samples were gathered outside thundercells by an onboard air sampler system for an atmospheric chemistry experiment. Two flights were made in close proximity to lightning-generating cumulonimbus clouds; however, no direct lightning strikes were experienced. Although no discernable lightning transients were recorded, many operational techniques were identified and established.

It was concluded that actual thundercell penetrations will be required to insure a better probability of collecting direct lightning strike data. It was also found that improved ground-based weather displays and lightning information data are required for making more effective launch decisions and test guidance. Finally, for storm penetration research flights, high caliber personnel expertise in the fields of weather radar operation and air traffic control will be required to provide real-time guidance to the research flight crew.

INTRODUCTION

The National Aeronautics and Space Administration is undertaking a storm hazards research program to extend the knowledge and understanding of atmospheric processes as they affect aircraft design and operations. To carry this out, the existence and intensity of the hazards of severe convective storms to aircraft operations are being measured using current technology. In the current phase, the Storm Hazards '79 program, preliminary flight tests with an NASA-owned F-106B aircraft were made on the periphery of isolated thundercells located within 100 n.mi. of the NASA-Langley Research Center using NASA-Wallops Flight Center weather radar support.

These flights, made under visual meteorological conditions, were conducted during August and September of 1979. This project is a continuation of the Storm Hazards '78 program, in which an NASA-owned Twin Otter aircraft was flown near isolated thunderstorms occurring near the National Severe Storms Laboratory in Norman, Oklahoma, and the NASA-Wallops Flight Center. The present program was conducted in preparation for upcoming research involving data collection during storm penetration flights.

In addition to research in the correlation of different storm hazards, two other experiments were planned. The F-106B research aircraft was modified so that airborne measurements of the lightning-generated electromagnetic environment of direct strikes could be made by a direct-strike lightning measurement system installed in the aircraft. To aid in the understanding of atmospheric pollution effects on the degradation of the ozone layer, air samples were taken outside thundercells by an onboard air sampler system for an atmospheric chemistry experiment. The air samples were analyzed for concentrations of CO and N_2O. The possibility of a significant amount of N_2O and CO being generated in the atmosphere by lightning has created wide scientific interest. Laboratory results are presented in reference 1.

The primary purpose of this paper is to describe the operational procedures using during the Storm Hazards '79 program and to present procedures for future programs involving thundercell penetrations. The lightning protection modifications and the lightning and air sampling data systems are described briefly. Finally, the storm hazards correlation data obtained during this limited test program are shown.

EQUIPMENT AND PROCEDURES

Test Aircraft

The test aircraft for the Storm Hazards program is a NASA-owned F-106B Delta Dart. The F-106B is a two-seat, high performance, land-based delta-wing, all-weather interceptor. The aircraft is powered by a single Pratt and Whitney J75-P-17 axial flow turbojet engine. The wings are of the full cantilever, stressed skin construction with a delta configuration and 60° sweep of the wing leading edge. The basic characteristics of the aircraft are given in table I. Figure 1 is a photograph of the aircraft, and a three-view of the aircraft is given in figure 2.

Test Aircraft Criteria

Several aircraft were considered for the role of penetrating moderate thunderstorms with the intention of taking direct lightning strikes for data purposes. Among those considered was a NASA-owned F-106B aircraft. After a comparison of the characteristics of the F-106B aircraft and other candidate aircraft, the F-106B was found to be the most suitable aircraft for the Storm Hazards research mission. The suitability of the F-106B aircraft for lightning research is discussed in reference 2, and the criteria used in the selection of this aircraft are also given in the following paragraphs.

Rugged construction.- The F-106B aircraft is a rugged fighter design with maximum design load factors of 6 to -2.4.

Two seats.- The F-106B aircraft is a two seat aircraft, permitting a flight observer or copilot to accompany the pilot during the mission.

Dual engine inlets.- As an aircraft flies forward, a lightning channel is swept aft along the fuselage, generally along one side or the other. The F-106B aircraft has dual inlets, which minimize the chance of engine flameout or compressor stall from lightning since only half of the inlet air can be disrupted when a lightning flash is swept along one side of the fuselage.

Autoignition and engine restart capability.- There are still some possibilities of engine flameout or compressor stall from the disruption of the inlet air by the lightning channel or from ingestion of water during flight through heavy precipitation. To alleviate the consequences of engine flameout the F-106B aircraft has a production autoignition system which triggers on fluctuations in burner pressure.

All-weather capability.- Aircraft can be modified to the desired research avionics standard for thunderstorm penetrations.

High altitude capability.- The F-106B aircraft is capable of operations to 15.2 km (50000 ft) with afterburner.

Windshield and canopy design.- The windshield and canopy design of the F-106B provide good lightning protection because of the metal windshield centerpost and canopy centerline and window frames. These metal structures will prevent punctures of the windshield and canopy by lightning strikes sweeping past, or by static charge accumulations. The metal framework will also minimize streamering from the crew helmets, and minimizes chances of electric shock to the crew.

Fuel system.- The closed, pressurized fuel system of the F-106B reduces the probability of fuel vapor ignition because the vents are normally closed; additionally, the vents are located beneath the wing in a region not likely to be exposed to lightning.

Lightning protection.- With the exception of two accidents caused by lightning surges entering the radome pitot heater systems, the U.S. Air Force F-106 fleet has been free of lightning strike effects. (The F-106 aircraft has one of the cleanest lightning damage records in the U.S. Air Force.) The pitot heater modification installed in the U.S. Air Force fleet has been installed on the NASA F-106B. Since this airplane is in a research configuration and is to be intentionally struck by lightning, several other lightning protection modifications have been installed. These modifications are discussed in the following section.

Availability of U.S. Air Force logistic support.- By choosing an F-106B aircraft, NASA-Langley was able to utilize the logistic support system and maintenance expertise of the Forty-eighth Fighter Interceptor Squadron based at the adjacent Langley Air Force Base.

Internal volume.- In the severe environment of a thunderstorm, external stores or data packages can be a liability because of gust loads, water erosion and lightning damage. Unlike most fighter aircraft, the F-106B has a large internal weapons bay suitable for conversion into an instrumentation bay. In addition, the NASA F-106B has an empty left forward electronics compartment since the MA-1 weapons system has been deleted.

Aircraft Lightning Protection Modifications

Since one of the primary missions of the Storm Hazards program is to collect direct lightning strike data, and the NASA F-106B is not a standard U.S. Air Force configuration, additional lightning protection was installed. The lightning protection modifications were based on the recommendations of Lightning Technologies, Inc., which was retained under contract for this purpose. This company was retained because of its recent experience in providing lightning protection modifications to the U.S. Air Force inventory of F-106 aircraft. The recommendations included attaching transient suppressors line-to-ground on each of the aircraft's 115 VAC power distribution busses which supplied power to any of the pitot or air data probe heaters, and installing the U.S. Air Force F-106 modification to protect the radome-mounted pitot-heater circuit. The production fiber glass vertical fin cap was flame sprayed with 4 to 5 mils of aluminum to provide a path of conductivity in that area, since the vertical tail is one of four prime points for initial lightning attachment on a delta-wing aircraft. The flame spray coating extended beneath the recessed screws at the base of the fin cap to provide electrical contact with the adjoining metallic structure. The flame-sprayed vertical fin cap is clearly visible in figure 1.

For the research instrumentation, four symmetrically-placed lightning current carrying conductors were used to connect the lightning current sensor ($\dot{I}$ sensor - to be described later) to the fuselage. Four conductors were required to maintain magnetic field symmetry near the $\dot{I}$ sensor. To minimize wall puncture and resultant damage to the radome and to minimize magnetic force effects, the conductors were routed so that there was some separation between the conductors and the radome wall. The bundle of conductors was also secured so as to prevent the bundle from flopping from the magnetic force between the bundle and flash channel sweeping aft along the outside of the radome.

The under-wing mounting lugs that had been used to hold experimental engines on the F-106B in a pre[illegible] research program were removed, as they passed from the outside into fuel tanks. Electrical conduits were also removed from the tanks.

Prior to the beginning of the Storm Hazards '79 program, discussions were held on whether the program should be flown using JP-5 (commercial designation: Jet A) instead of JP-4 fuel (commercial designation: Jet B). Some observers have concluded that turbulence would produce misting of Jet A and Jet B fuel. For Jet A fuel, misting results in a lowering of its lean altitude-temperature flammability limit to encompass the flight envelope; however, two other factors will act to raise the Jet A lean limit during flight in the F-106B. The first of these is that the F-106B tanks are pressurized above ambient, a factor which requires that the Jet A fuel temperature be even higher than the flash point (100° F) to produce an ignitable fuel-air mixture. The second factor is the replacement of fuel with air as fuel is burned off, thereby continually leaning out the Jet A vapor in the tanks and tending to keep it nonflammable. Both of these factors, conversely, will lean out the otherwise over-rich Jet B (JP-4) vapor expected in warm fuel tanks, acting to bring this vapor within the flammable range.

It also has been shown (ref. 3) that about 10 times more energy is required to ignite a Jet-A (JP-5) mist than a mist of Jet-B (JP-4) because Jet-A droplets evaporate much more slowly. Once ignited, the rate of Jet-B flame spread has been shown (ref. 4) to be higher than that for Jet-A (JP-5), again due to the higher volatility of Jet-B. Finally, experience over the years has shown that Jet-B is much more hazardous, under many conditions, than Jet-A. There have been about 10 confirmed lightning-related in-flight fuel tank explosions since 1958 and all of these involved Jet-B (or gasoline - a fuel of similar volatility - see reference 3). Therefore, Jet-A fuel was used in the F-106B during the Storm Hazards '79 program based on the recommendations of both the U.S. Air Force and Lightning Technologies, Inc.

Aircraft Data Systems

Introduction.- Four independent aircraft data systems were installed for the Storm Hazards '79 program: direct-strike lightning instrumentation system, atmospheric chemistry data system, Stormscope and C-band transponder. For emergency purposes, the pilot had a master power switch in the forward cockpit (see figs. 3 and 4) which could simultaneously control power to all instrumentation systems except the C-band transponder. In regular operations, however, the switch was left in the "normal" position, allowing each system to be operated through its own control system. The four aircraft data systems are described in the sections which follow.

Direct-strike lightning instrumentation system.- The direct-strike lightning instrumentation system consisted of five electromagnetic sensors located on the aircraft, pilot's and operator's controls in the cockpit, a shielded/isolated enclosure for the recorders in the aircraft weapons bay, and shielded cables and fiber optic links to transmit data signals and control signals to the shielded/isolated enclosure. An aircraft schematic showing the locations of the lightning system components is given in figure 3, and a block diagram of the system is given in figure 5.

An inductive current probe ($\dot{I}$ sensor) was installed inside the aircraft radome, attached to the fitting piece which secures the metal nose boom to the radome. The $\dot{I}$ sensor location is indicated in figure 3, and a photograph of the interior of the radome, showing the $\dot{I}$ sensor in place, is given in figure 6. The sensor measured the time rate of change of the total attachment current to the nose boom, hence the term "$\dot{I}$."

There were also two flat-plate antennas, or $\dot{D}$ sensors, on the aircraft. One sensor was installed beneath the aircraft nose ahead of the nose wheel well (see figs. 3 and 7); the second sensor was mounted on the left side of the vertical tail (see figs. 3 and 1). The inside of one of the $\dot{D}$ sensors is shown in figure 8. The $\dot{D}$ sensors responded to time rate of change of electric flux density; therefore, the data must be integrated to obtain the electric field intensity.

The final two sensors of the five sensor direct-strike lightning system were multigap loop antennas, or $\dot{B}$ sensors. The $\dot{B}$ sensors were installed on the top of the fuselage forward of the vertical tail (see fig. 3). One of the $\dot{B}$ sensors is shown attached to an aircraft mounting plate in figure 9, and with the fiberglass weather cover attached in figure 10. The left $\dot{B}$ sensor cover can be seen on the aircraft fuselage above the wing in figure 1. One sensor was oriented to sensor magnetic fields corresponding to wingtip-to-wingtip strikes (transverse), with the other aligned to sense magnetic fields corresponding to nose-to-tail strikes (longitudinal). The two sensors were designed to respond to the time rate of change of the magnetic flux density, and the data must be integrated to obtain the magnetic field intensity.

Sensitivity of the lightning instrumentation system was established for the direct-strike measurement, and was based on field changes and current changes in 0.1 μsec. These quantities are shown in table II for the five lightning measurements. One electric flux density measurement (tail-mounted $\dot{D}$ sensor) was made more sensitive than required for the direct-strike environment in order to examine "pre-strike" electric field radiation. It was anticipated that this channel would saturate during a nearby or direct lightning strike, recovering after the field diminished.

The direct-strike lightning recording system was located in an isolated, shielded enclosure suspended in the aircraft weapons bay (see fig. 3 for location). The direct-strike lightning recording system, shown in a laboratory without the cover in figure 11, contained two expanded memory Biomation recorders, one 14-track magnetic tape recorder, a two-track 6-MHz magnetic tape recorder, and a time-code generator. The wide-band analog recorder (6 MHz) was used to record the lightning scenario and was supplemented with the two high sample-rate digital transient recorders (Biomations). The Biomations utilized an in-house developed, expanded 131,000-word memory capacity for increased time duration of specific times of interest. Each of the Biomation recorders automatically recorded the lightning induced electromagnetic signal from a preselected sensor/transmission path combination which exceeded a pre-set trigger level. Each Biomation recorder could record 100,000 samples in 0.001 sec, playing them out over 5 sec onto the 14-track tape recorder. During the playback cycle, the Biomation recorders do not respond to any further electromagnetic signals, but automatically reset to the record mode at the completion of the playback cycle. The endless loop data storage technique employed by the Biomation recorders circumvented problems associated with oscilloscopic techniques.

Power to the system was provided by an electric motor mounted outside the enclosure, which transmitted power to a generator in the shielded enclosure through an insulated, flexible shaft. Further system integrity and immunity from induced electromagnetic effects was accomplished by fiber-optics signal transmission links and shielded system enclosures.

A feature of the development system was the capability of all five sensors to transmit their output to the shielded enclosure by coaxial transmission lines or by fiber-optic links. The choice of sensors and transmission links for recording had to be made before each flight so that appropriate adjustments could be made inside the enclosure while it was removed from the aircraft. There was a separate, battery-powered fiber-optic transmitter for each of the five sensors which were switched on prior to flight.

The sensor/transmission link configuration for the first instrumentation data flight on August 28, 1979, is shown in figure 12(a). This configuration was maintained through the flight of September 19, 1979. The 50 MHz low pass filters shown in series with the Biomation recorders were installed to provide pre-sample filtering of the data. For those sensors with the dual output lines, the recorded voltage was the differential between the two lines, whereas the recorded voltage for the single output sensors was the difference between the line voltage and ground. The configuration was changed, as shown in figure 12(b), for the flight of September 22, 1979. In the second configuration, no fiber optics were used and the $\dot{I}$ sensor used a single output line.

The final component of the direct-strike lightning system was the cockpit control panel. The system control panel was located on the left side instrument console in the aft cockpit for use by the flight observer (see fig. 3). The control panel, shown in figure 13, had three control switches to: (a) control master power to the lightning system; (b) control power in the enclosure; and (c) to turn the 6 MHz and the 14-track magnetic tape recorders on. Each of the two Biomation recorders in the system had a status light on the control panel wired through the "instrumentation power" switch. Presence of a light indicated that the Biomation was in the record mode and able to take data. Finally, there was a digital elapsed-time display keyed to the "recorder" switch. This display provided an in-flight readout of record time on the tape recorders. A detailed description of the direct-strike lightning measurement system may be found in reference 5.

Atmospheric chemistry data system.- The onboard equipment for the atmospheric chemistry experiment (ACE) consisted of a system for collecting air samples near thunderstorms. The ACE sampler system consisted of 24 stainless steel collecting bottles, an air pump, associated plumbing, and an operator's display and control panel in the aft cockpit. The locations of the ACE system components are shown in figure 3. The bottles, pump, and plumbing are shown in figure 14, and in figure 15 are shown mounted in the right forward section of the aircraft weapons bay. The air samples were taken through a heated pitot head mounted on the forward end of the right-side weapons-bay door, as shown in figure 16. The air samples were taken to the pump and bottles from the sampler head by the flexible tygon tube shown in figure 14. The pump was used to pressurize the bottles with air samples regardless of aircraft altitude.

The ACE sampler display and control panel, figure 17, was located on the right side instrument panel in the aft cockpit. The power switch controlled aircraft power to the sampler pump. After the pump was turned on, air samples were taken by using the desired "bottle select" switch (only one bottle could be filled at a time), and then by using the "bottle fill" switch. The "bottle expended" light illuminated when the matching "bottle select" switch was used at the beginning of the sample and stayed lit after being used. The "fill indicator" light was illuminated only as long as the bottle was actually being filled. The operator turned off the "bottle fill" switch when the "fill indicator" light extinguished. Once a bottle was filled, it could not be refilled during that flight.

Following a flight, the bottles were taken to a gas analysis laboratory at NASA-Langley for analysis using gas chromatographs, mass spectrometers and infrared spectrophotometers. No onboard or real-time gas analysis was possible or desired.

Stormscope.- A commercially available lightning detection and mapping system was installed in the test aircraft to provide a real-time indication of lightning location to the flight crew. The control unit and a master display were mounted in the forward cockpit, and a repeater display unit was installed in the aft cockpit (see fig. 3). The display installation in the forward instrument panel is shown in figure 18. The Stormscope system compared the strength of each discharge to several models of lightning strokes to compute a pseudo range. The antenna was directional so that lightning location relative to airplane heading at the time of the discharge (relative azimuth), was measured directly. The pseudo range and relative azimuth of each measured discharge was shown on the master and repeater display unit as a dot representing the relative location of the discharge from the aircraft. The Stormscope memory could hold up to 128 separate discharges, after which the oldest points were replaced sequentially by the new points. The memory and displays could be cleared at any time by using the "clear" switch on the control unit. Generally, the display should be "cleared" whenever there is an airplane heading change. The maximum range of the Stormscope system could be adjusted to 40 n.mi., 100 n.mi., or 200 n.mi The Stormscope data were not recorded during the Storm Hazards '79 program, but will be recorded during future tests.

C-band transponder.- A C-band radar transponder was installed in the test aircraft for NASA-Wallops radar tracking purposes. The transponder (see fig. 3 for location) was passive, transmitting only when interrogated by the NASA-Wallops C-band radar. The unit was activated on the ground prior to each flight and could not be controlled by the flight crew in flight. The C-band radar and transponder were required because the NASA-Wallops SPANDAR radar could not accurately skin track a target as small as the test aircraft while simultaneously contouring weather. No onboard measurements were made from the transponder.

Test Facilities

Wallops Flight Center.- Radar reflectivity of precipitation within 100 n.mi. of NASA-Wallops Flight Center was measured by the NASA-Wallops SPANDAR radar, which is described in Table III. For the Storm Hazards program, the reflectivity data was displayed in real-time on a color television monitor in the SPANDAR control room. The SPANDAR crew used the real-time display to provide guidance to the flight crew on thundercell developments. The television display was also recorded on video tape for post-flight viewing, but no quantitative data were taken from the video tapes.

An aircraft-mounted C-band transponder was tracked by a NASA-Wallops C-band tracking radar. The C-band radar data was recorded on digital magnetic tape for post-flight computer data reduction. The reduced data included listings of such parameters as time, altitude, velocity, latitude, longitude, and North/South and East/West distances of the aircraft from the SPANDAR radar site. The computed distances were also cross plotted to give a continuous plotted record of the aircraft ground track. Details on the C-band tracking radar may be found in table III.

Voice communications were used to relay real-time information concerning storm cell location and reflectivity and to correlate data occurrences. The voice communications were recorded on the SPANDAR video tapes and on an audio tape recorder for post-flight transcription.

During the flight of September 3, 1979, the changing electrostatic field of the storm was recorded by a portable system located adjacent to the SPANDAR control site. The equipment consisted of a fast and slow antenna to measure the magnitude of the stroke, type of stroke, time of occurrence, and number of discharges. The information was displayed in real time on strip charts and was used to supplement the SPANDAR real-time flight guidance to the test aircraft.

Langley Research Center.- Launch control for each of the Storm Hazards '79 flights was located in the NASA-Langley Flight Service Office, from which telephone and radio communications with all the units involved in the flight could be maintained. As there was no display of the NASA-Wallops SPANDAR radar data at Langley, two other radars were used to provide a weather overview for the personnel in NASA-Langley launch control. First, radar reflectivity from a WSR-57 weather radar at Patuxent River, MD, was transmitted by telephone line to a thermal printer in the Flight Service Office. For each new scan image, a separate telephone call to the radar facility was required.

A sample Patuxent River WSR-57 telephone facsimile plot is shown in figure 19. The range rings are located at 25 n.mi. intervals from Patuxent River with a maximum range of 125 n.mi. The shaded areas in the facsimile depict those areas in which precipitation is occurring. Much of the shaded area within 25 n.mi. of Patuxent River is radar ground clutter, not weather, however. The precipitation, or reflectivity, shadings are defined in table IV. In figure 19, the first two levels of reflectivity are discernable, indicating a maximum reflectivity of 41 dBZ. The hand annotated comments were placed on the radar image by the Patuxent River technicians. Because of the poor image resolution, the facsimiles were useful only to give a weather overview.

On several flights, the Langley Air Force Base FPS-77 weather radar was also used to provide weather information prior to launch. The FPS-77 radar is located at the Langley Air Force Base Tower (on the opposite side of the field from Launch Control), and does not have any remote terminals elsewhere on the base. Therefore, whenever a radar scan was desired, the project personnel had to visit the tower. In addition, the radar cannot scan continuously; each 360° azimuth scan or vertical scan was made separately by a U.S. Air Force technician. The FPS-77 was valuable, however, in that the radar scan was in real time, while the WSR-57 radar scan transmitted by telephone could be several minutes old. The FPS-77 was also valuable because it covered a geographical area south of the SPANDAR coverage below the SPANDAR line of sight. No records or hard copies were available of the FPS-77 information.

Test Procedures

Basic ground rules.- Flight activities for the Storm Hazards '79 program consisted of flying the NASA-owned F-106B aircraft in the vicinity of isolated thundercells, usually within 100 n.mi. of Wallops Flight Center. Beyond 100 n.mi., the NASA-Wallops data support, particularly from the SPANDAR radar, became tenuous. Only one storm flight, on September 28, 1979, was made outside the NASA-Wallops support area. Because of inadequate "all weather" avionics during this test period, no thunder cell penetrations were attempted and all operations were limited to daylight, VFR conditions. This restriction (which will be alleviated for future programs) also meant that no departures or arrivals from Langley were planned in IFR conditions. In the event that IFR weather developed at Langley during a flight, and in case of emergency, a number of diversionary airfields were chosen. Each airbase had an 2438 to 3048 m (8000 to 10000 ft) runway with adequate arresting cable systems for the F-106B tail hook. The diversionary fields are shown on the map in figure 20.

On several flights a NASA-Langley T-38 aircraft was used for photographic and safety chase. Provisions were made for having the T-38 rendezvous with the F-106B after a direct lightning strike to do a visual check of the F-106B. An alternative post-lightning strike procedure was also planned to eliminate the potential complexities in trying to rendezvous two aircraft in thunderstorm areas. In this alternative procedure, following a direct strike, the F-106B aircraft would return to Langley for physical inspection and lightning-system checkout. It was hoped that after experience had been gained during the program, a less conservative operational approach could be adopted in which, following a direct lightning strike to the aircraft, the pilot would fly to an area out of the vicinity of the thundercells. The pilot would then check all aircraft flight instruments for anomalies, and the flight observer in the aft cockpit would check the data systems for anomalies. If no damage was apparent, the mission would continue; if faults were noticed, the aircraft would return to Langley. Since no lightning strikes were taken by the aircraft, the safety chase or return-to-base procedures were in effect throughout the program and will be continued for the upcoming programs.

All flight missions were made with a two-man crew. A research pilot flew the mission from the forward cockpit. A pilot or test engineer served as observer in the aft cockpit and operated the lightning and atmospheric chemistry data collection systems. The observer helped direct the flights, but all final decisions in the air were made by the research pilot. The observer could also provide a safety back-up if the research pilot was momentarily affected by flash blindness. The chances of both crewmen being blinded was slight as the crewmen were rarely looking in the same direction.

Mission techniques.- The initial planning for a storm flight was based on the weather forecasts by the NASA-Langley Flight Service Office, and on occasion, by the Langley Air Force Base weather forecasters. A key aid in making the launch decision was the telephone-transmitted radar facsimile from the WSR-57 weather radar at Patuxent River, MD. For some flights, the project personnel went to the Langley Air Force Base Tower to get a real-time weather radar scan from the U.S. Air Force's FPS-77 radar. When possible, NASA-Wallops personnel surveyed areas of interest with their SPANDAR radar, using the real-time video system installed for this program. Once a candidate thundercell was located, a launch time was chosen for the mission. Because of the limited endurance of the NASA F-106B aircraft, the success of each mission was highly dependent on the quality of forecast information that was available to determine the most suitable launch time.

Launch control was also responsible for monitoring the weather situation at Langley to be sure that if conditions at Langley became IFR, the research flight would be terminated in time for an alternate field to be used.

During the flight, NASA-Wallops tracked the aircraft using a C-band tracking radar. Using the C-band track and the SPANDAR radar video display, it was possible to advise the flight crew on thundercell development and changes in cell reflectivity. The two displays could not be superimposed; therefore, the real-time comparison of aircraft location to thundercell reflectivity was made by the operators, using the adjacent C-band and SPANDAR displays.

Since the airplane was not suitable for IFR flight during the Storm Hazards '79 tests, six VFR flight paths were recommended for taking the aircraft into areas where lightning may be found outside of the storm. These paths, which are discussed in reference 2, were: beneath the base, beneath the anvil, between clouds, above the cloud tops, and around the turret. Reference 2 also presents statistical data which suggests that the highest probability for taking lightning strikes outside of thundercells occurs at or around the freezing level. Therefore, the path usually used during the Storm Hazards '79 flights was a series of VFR passes back and forth outside the storm at the freezing level.

The Stormscope was used during the flight to look for areas of lightning activity in the thunderstorm cells. If the Stormscope showed no activity, the data systems were not activated. When a data pass was to be made, the lightning data system was turned on while the aircraft was still several miles from the thundercell, and remained on as long as the aircraft was in the vicinity of the thunderstorm cell. Air samples for the atmospheric chemistry experiment were taken periodically during the passes by the thunderstorm cells. Post-flight debriefings of the research pilot and observer occurred after each flight.

RESULTS AND DISCUSSION

Summary Chronology of Flight Operations

The 15 flights made during the Storm Hazards '79 program are summarized in chronological order in this section. Following the chronology, the two storms in which there was visible lightning activity (August 28 and September 3, 1979) are discussed in detail. The pilot, flight observer, flight duration and fuel usage for each of the 15 flights is given in table V.

August 23, 1979

Functional check flight. Atmospheric chemistry experiment sampler system and direct-strike lightning measurements system onboard for weight and balance purposes only. Hydraulic line to ram air turbine pulled loose from fitting, causing failure in primary hydraulic system. Aircraft recovered safely. T-38 chase aircraft used.

August 28, 1979

Storm flight. Aircraft flown near visible lightning from storm over Yorktown, VA. Pilots noted three near lightning strikes, two occurring at the same time. No discernable lightning transients were recorded, although the aircraft was being operated at the cloud edge. If the lightning was contained within the cell, it was within several km of the aircraft. Three airborne air samples taken, but unusable due to cross-contamination problem caused by fault in air sampler plumbing design.

August 30, 1979

Continuation of functional check flight. Flight terminated due to failure in cabin pressurization system. At 8.2 km (27000 ft) altitude, cabin pressure was also at 8.2 km (27000 ft).

September 3, 1979

Storm flight. Flight along southeast edge of line of storms near Crisfield, MD. Pilots noted visible lightning. No discernable lightning transients recorded. Aircraft may have been within several km of lightning. Air sampler not carried. Aircraft injested sea gull down right intake during touch-and-go at end of mission. Aircraft recovered using runway arresting cable. Engine removed for damage inspection. No damage found and engine reinstalled. Five weekdays, seven days total, lost because of sea gull injestion.

September 11, 1979

Completion of functional check flight and weapons bay temperature survey. First flight with weapons bay temperature system installed. Temperatures found to be lower than expected (see table VI for temperature survey data). The maximum temperature of 115° F was less than the critical temperature for the data components in the weapons bay. As an operational temperature precaution, however, the data systems were not turned on until after takeoff. Air sampler system back onboard. Cabin pressurization system operational.

September 14, 1979

Storm flight. Flight was made in vicinity of several storms stretching from Cape Charles, VA, to Patuxent River, MD. Little or no visible lightning. All 24 air samples taken; normal readings of CO and N_2O found, as expected.

September 18, 1979

Pilot familiarization flight and electromagnetic interference (EMI) test for lightning experimenters. Electrical and data systems cycled with lightning system tape recorders running. C-band and SPANDAR radars also locked on to aircraft to EMI check. Problem experienced in using air sampler system - air sampler system improperly reset following reinstallation after September 14, 1979, flight. First flight for Stormscope.

September 19, 1979

Pilot familiarization flight and observer checkout.

September 22, 1979

Storm flight. Flight over the Atlantic near Oceana, VA. No lightning seen by crew. Unable to take air samples because sampler system not properly reset - repeat of problem on flight of September 18, 1979.

September 26, 1979

Pilot familiarization, airspeed calibration and T-34C photographic chase. Comparison of nose boom pitot-static system (primary flight instruments and central air data computer) to undernose pitot-static system (secondary flight instruments). Flight showed need to compare two pitot-static systems with similar airspeed indicators.

September 27, 1979

Pilot familiarization flight and airspeed calibration. Stormscope display in forward cockpit replaced with airspeed indicator attached to undernose pitot-static system. Results showed that two systems are close at high speeds with divergent readings at lower airspeeds. WVEC-TV, local ABC affiliate, covered take-off and interviewed pilot and Program Manager for evening news of September 29, 1979.

September 27, 1979

Pilot familiarization and observer checkout.

September 28, 1979

Pilot familiarization and movie documentation. NASA movi shot on ramp and in flight from T-38 chase aircraft.

September 28, 1979

Storm flight. Aircraft flown along line of thunderstorms extending from Franklin, VA, to Elizabeth City, NC. Since no lightning was seen by the crew, no data taken.

October 2, 1979

Pilot familiarization. Last flight of Storm Hazards '79 program. Following flight, aircraft was grounded for preparation for Storm Hazards '80 program.

August 28, 1979 - Yorktown Storm

On the afternoon of August 28, 1979, a number of thunderstorm cells were developing over eastern Virginia. Based on the WSR-57 weather radar facsimiles available in the NASA-Langley Flight Service Office, a decision was made to launch for several thunderstorm cells in the vicinity of Richmond, VA. During the preflight preparations, the facsimile shown in figure 21 was transmitted, showing that a cell had developed much closer to Langley in the vicinity of Yorktown, VA. The Yorktown storm was ideal in the respect that it was very close to both Langley and Wallops, and the flight crew could start the test flight paths almost immediately after takeoff. The Yorktown thunderstorm cell is located in the lower left hand corner of the box superimposed on figure 21. This box covers an area from 20 to 90 km south and 70 to 130 km west of Wallops and is shown in detail in figure 22. Referring to figure 21 and table IV, it can be seen that the Yorktown cell was a level two storm, with a radar reflectivity between 31 and 40 dBZ.

Takeoff occurred at 20:42:13 GMT, with C-band radar acquisition of the aircraft transponder at 20:46:13 GMT at an altitude of 5.4 km. The aircraft ground track given by the C-band tracking data is shown in figure 22. The ground track has been annotated at 5-minute intervals with time and altitude from the C-band radar data. The basic outline of the Yorktown storm cell from the 20:21 GMT WSR-57 radar facsimile (fig. 21) has been plotted to scale on figure 22. During the 25 minutes between the time of the WSR-57 facsimile transmission and the C-band radar acquisition, the cell grew and moved to the northeast to the location outlined by the loop in the aircraft ground track between points a and b. The continued northeast movement can be seen in the drift of the aircraft ground track to the northeast.

The pilot described the storm as follows: "It was fairly well defined visually, especially along the leading edge. It was young and moving constantly to the northeast and was not imbedded in too much low level stratus. The main storm cell was about 16 km (10 miles) in diameter and the cloud extended from about 1.2 km (4000 ft) above ground level."

The first data pass was a complete circle of the storm. Again returning to the pilot's description: "The leading edge, or northeast portion, contained the darkest clouds, the most visible lightning and the most vertical definition. As we maneuvered the airplane in as close as possible to the main cumulus cloud, we observed the first close lightning strike. It was a vertical stroke about 0.5 km (500 yards) to the left of the airplane between us and the main cloud. A static snap was heard in the headset, but no thunder was audible above the engine noise." According to the voice transcript, this near strike occurred at 20:54 GMT (see fig. 22). This lightning event was not recorded by the direct-strike lightning system as the event occurred during one of the periods when the system was turned off.

Following the initial circuit of the thundercell periphery, it was decided to conduct the remainder of the tests along the northeast face of the storm. The rationale is given by the pilot: "As we completed the first circle, the 'back side' or trailing edge of the storm was found to contain smaller towers and a general trail of lower level stratus and cumulus. This made the storm almost impossible to work from the 'back side' or to continue to circle and still stay in visual meteorological conditions at an altitude that was near the freezing level 4.6 km (15000 ft). This fact led to the decision to work the leading edge of the storm in a series of tracks basically from the southeast to the northwest and back. In this manner, the aircraft could be maneuvered in the clear at any altitude from ground level to the top of the storm. This also seemed to be the portion of the storm where we had the greatest probability of getting a direct lightning strike without entering the storm."

The observer in the aft cockpit described the five passes as follows: "We made a number of passes along this side of the storm from about 3.6 km to 5.5 km (12000 ft up to 18000 ft) as close to the clouds as we could fly, often inserting a wingtip into the clouds. The air was very smooth at all times, which was considered strange with so much electrical activity. Even the last run made under the base of the clouds (aircraft position e in figure 22) was relatively smooth with no precipitation. As we varied the altitude, the contour of the cloud changed, allowing us to get closer to the center of the cell as we stayed in VFR conditions."

At 20:58 GMT the crew observed a pair of near strikes to the aircraft. The direct-strike lightning instrumentation system did not record any discernable transients. The location of the aircraft at the time of the event is marked in figure 22. The pilot described the event as follows: "The next close lightning was observed as we tracked back and forth in front of the advancing storm. The airplane was headed southeast when the stroke appeared on the right side of the airplane. It seemed to originate from the main storm cloud and travel under the nose of the airplane and reappear as a quick flash on the left of the airplane. The same sort of static snapping noise was again heard in the headset simultaneously with the observed lightning. The pilot comment at this point was that we had possibly been struck but that all aircraft systems remained normal." After the flight, no physical evidence of a direct lightning strike could be found.

An air sample bottle was filled immediately after each near strike at 20:54 GMT and 20:58 GMT. A third air sample was taken at an altitude of 1.2 km (4000 ft) while flying under the storm on the last pass (near point e in figure 22). Unfortunately, the three air samples were found to be unusable because of a system design flaw which permitted the bottles to cross contaminate one another.

The data mission was terminated at 21:11:59 GMT and the aircraft landed at Langley at 21:27 GMT. No other close lightning strikes were observed after 20:58 GMT.

September 3, 1979 - Crisfield Storm

The Crisfield storm of September 3, 1979, was not a single large cell that could be circled, but was a multicelled squall-line type with the cells imbedded in a continuous cloud which covered many miles. The Patuxent River WSR-57 weather radar facsimile transmitted at 18:50 GMT is shown in figure 23. No line of cells is located in the northwest (upper left) corner of the box superimposed of the figure. The box in figure 23 shows the limits of the C-band plot coverage that is given in figure 24. The aircraft ground track in figure 24 was generated in the same manner as in figure 22, and the outline of the storm is scaled from the 18:50 GMT WSR-57 facsimile shown in figure 23.

No thunderstorm penetration was made during the portion of the ground path marked by point 1 in figure 24. The aircraft passed through that area about 7 minutes prior to the time of the WSR-57 contour by which time the storm had moved to the east, covering the area traversed earlier by the F-106B aircraft. As was the case in figure 21, the storm in figures 23 and 24 is apparently a level 2 storm, with a radar reflectivity between 31 and 40 dBZ.

The decision to launch for the Crisfield line was made at 18:04 GMT, with takeoff occurring at 18:36 GMT. C-band radar acquisition occurred at 18:39:03 GMT at an aircraft altitude of 4.3 km.

The description of the mission from the observer in the aft cockpit follows: "We flew along the southeast side of the squall line until we came to a very dark area occassionally lit up with lightning. Wallops radar (SPANDAR) confirmed this area to be the most intense, with heavy precipitation, so we concentrated our flight activity along this area. The cloud formations along the edge of the storm were unusual; there were stratus fingers extending out into the clear air forming a cave or tunnel. We saw the dark clouds on the storm side, clouds above and below us with the sun shining on the other side. (There were clouds above and below the aircraft with the storm on one side of the aircraft and clear sky on the side away from the storm). The air was smooth in these tunnels, and the lightning was further inside the storm clouds, less visible to the aircraft than that observed in the Yorktown storm. We did not see the lightning bolts, but rather the clouds lit up. When we descended below the base of the storm, we experienced moderate to heavy turbulence and saw a heavy rain shower further under the storm with lightning. The rain probably indicated the location of the cell itself, which explained why the lightning appeared to be so far from the aircraft."

The pilot and observer either saw lightning visually or heard the lightning static on their headsets on 11 occasions. The airplane positions at the time of these events are shown in figure 24. Their comments were: event 1 - "hearing lightning, but don't see it;" event 2 - "between layers - hear a lot of lightning; not seen it;" event 3 - "saw first lightning to west;" event 4 and 4a - "saw more lightning at 2 o'clock. Lightning in precipitation on right, one-fourth mile;" event 5 - "have excessive lightning at 9 o'clock; right in edge of precipitation;" event 6 - "lightning all encased in cloud. Can't see any distinct lightning;" event 7 - "saw more lightning at 2 o'clock;" event 8 - "got more lightning to west. Clouds glowing;" event 9 - "lightning to the right;" event 10 - "saw more lightning - cloud to water;" event 11 - "lots of lightning." The direct-strike lightning measurement system recorded no discernable transients; the air sampler system was not carried on this flight.

A very distinct gust front was visible on the water below the storm moving to the east with the line. The gust front was visible because of the wall of rain behind the front and the change in surface texture of the water at the front. Ahead of the gust front, the surface was smooth, while behind the gust front, there were whitecaps on the water. The aircraft flew roughly parallel to the gust front on the calm side. Some periods of moderate turbulence were found near the gust front.

The data mission was terminated at 19:23:40 GMT, and the aircraft landed at Langley at 19:27:50 GMT. During a touch-and-go landing, a sea gull was injested into the engine through the starboard intake, and the touch-and-go was aborted, followed by drag chute and tail hook deployment. The aircraft was recovered safely.

Lightning Instrumentation System Initial Flight Test Results

The objective of the lightning measurement portion of the Storm Hazards '79 program was to better and more completely define the lightning hazard to digital avionics through:

1. the development, proof, and demonstration of an advanced instrumentation system of superior capability, and

2. the collection of research data using the advanced instrumentation while experiencing in-flight lightning strikes.

Only the development portion of the first objective was met this year because the aircraft experienced no direct lightning strikes, and consequently no research data were collected. However, the advanced instrumentation system was functionally checked in a flight environment.

The lightning instrumentation system was operated for five flights in the period from August 28 to September 22, 1979. The flight operation on September 18, 1979, was devoted to interference tests for the lightning instrumentation system, and was conducted in the following manner. Just prior to aircraft takeoff, the lightning instrumentation system was activated and the following aircraft and other experimental systems were cycled on and off: VHF communications, UHF communications, Stormscope, Atmospheric Chemistry Experiment data system, pitot-ptobe heater, canopy heater, landing and taxi lights, and navigation lights. A C-band tracking beacon was on during the entire test. Minutes later, at 4.7 km (15500 ft) altitude, these same systems were cycled on and off again. Additionally the aircraft was tracked by the NASA-Wallops SPANDAR radar which was turned off near the end of the flight.

Examination of the recorded information revealed no interference to the lightning instrumentation system from other electrical systems on the aircraft, or from the NASA-Wallops radar.

Flights on August 28 and September 3, 1979, were made in the vicinity of electrically active storms, and several transients were recorded on the 6 MHz wideband recorder, but none were recorded via the expanded memory digital transient recorder.

Subsequent system checks revealed an intermittent electrical short in the cable conducting the signals to the 6 MHz recorder which produced transients similar to those recorded during the flights of August 28 and September 3, 1979. It was concluded that the intermittent short in the signal cable was the source of the transient signals which were recorded on August 28 and September 3, 1979. The remaining two instrumented flights did not encounter electrically active storms and no transients were recorded by the system.

Examination of pre-flight and post-flight information accumulated showed that the system components functioned satisfactorily in the aircraft environment throughout the flight profile necessary for lightning research. Complete verification of the lightning instrumentation system remains to be accomplished.

Although the aircraft flew within 0.5 km (500 yards) of lightning (August 28, 1979), no transients were recorded. It should be pointed out that the lightning instrumentation system was designed to measure and record direct lightning strikes. Therefore, to ensure a better probability of collecting direct-strike lightning data, the aircraft is being prepared to be flown in an environment more conducive to taking direct lightning strikes, that is, within the thunderstorms. The aircraft preparations will consist largely of installing avionics for full IFR operations.

Operational Factors and Recommendations

The operations of the Storm Hazards '79 program showed that there was a need for real-time weather radar displays in the NASA-Langley Flight Service Office to support the launch time decision and for coordination during the test flight. It was difficult to determine the real-time locations and intensities of thundercells using the facsimile copies of the Patuxent River WSR-57 output and the real-time output of the U.S. Air Force FPS-77 radar. The Patuxent River information was not available continuously, and was not available when the telephone lines to Patuxent River were busy. Also, the image resolution was too poor to permit detailed data analysis. It was not possible to use the FPS-77 during the course of the flight because the radar site was several miles from launch control. Although telephone communications were maintained with the NASA-Wallops SPANDAR radar personnel, the lack of a visual display at NASA-Langley and the maximum range of 100 n.mi. from NASA-Wallops limited the SPANDAR's utility. Based on the operations conducted during the Storm Hazards '79 program, it was concluded that a real-time weather radar display installed in the NASA-Langley Flight Service Office would provide a basis for significantly improved research results. With an on-site weather radar display, the personnel in launch control can improve the launch-time decision process, as well as maintain a better overview of the mission as it progresses, and advise the flight crew of weather developments in the vicinity of Langley.

Although real-time weather information is invaluable, radar displays do not show lightning activity. Typically, the aircraft was launched without reports on lightning. The flight crew would search for lightning after they had flown to the vicinity of a candidate storm, searching visually and with the Stormscope. The crew also listened on their headsets for the characteristic static crackle of lightning. On the storm flights of September 14, September 22 and September 28, 1979, although the prelaunch radar information looked promising, the storms contained little or no lightning activity. Therefore, it was additionally concluded that a Stormscope system installed in the Flight Service Office to supplement the proposed weather radar display would provide additional information to improve research results. By combining the weather radar and Stormscope displays, the project personnel would be able to choose, before launch, those storms with the highest levels of lightning activity. The personnel also should be able to keep the flight crew appraised of changes in lightning activity during the mission. It is also felt that the Lightning Detection and Ranging (LDAR) system recently acquired by NASA-Wallops could be very useful for locating areas of lightning activity for real-time operational vectoring.

Because of the speed with which thunderstorms can build and dissipate, it is imperative that the reaction time for launching the aircraft be as short as possible. Also, for operations away from NASA-Langley, pre-flight and post-flight tasks should be such that they can be accomplished with minimum ground support and effort. For these reasons, certain minor changes are planned in the mechanical configuration of the lightning instrumentation system enclosure, the lightning sensor electronics enclosures, and all other data systems which will greatly simplify the crew efforts in making the necessary pre- and post-flight checks and adjustments.

This year's experience with the lightning instrumentation system has pointed out the need for an "end-to-end" system test - from sensors to tape recorder. The test will be based on excitation of a flight-ready aircraft and instrumentation system with an electrical transient generator and recording the sensor responses for analysis.

For the actual penetration flights planned for the future, the pilots felt that high caliber personnel expertise, in addition to that used in the Storm Hazards '79 program, will be required. One pilot said" We need radar capability to keep us out of hail and the people to use it, and we need an air traffic controller to integrate us into the positive controlled traffic in IFR conditions." Although airborne weather radar will be installed in the F-106B aircraft, the airborne crew will be almost totally dependent on the ground-based equipment and crew to keep the aircraft clear of the hail hazard and to provide escape vectors and headings in the event of an inadvertant hail encounter.

CONCLUDING REMARKS

A storm hazards research program is being undertaken by NASA-Langley to extend the knowledge and understanding of atmospheric processes as they affect aircraft design and operations. In the current phase, the Storm Hazards '79 program, preliminary flight tests with an NASA-owned F-106B aircraft were made on the periphery of isolated thundercells located within 100 n.mi. of NASA-Langley using NASA-Wallops weather radar support.

Fifteen total flights were made, of which five were storm flights. In two of these flights, the aircraft was operated in close proximity to lightning-generating cumulonimlous clouds. No direct strikes to the aircraft were experienced, nor were any discernable electrical transients recorded.

The principal benefits of this program were to provide: a verification of the flight worthiness of the NASA F-106B airplane for VFR storm research testing; establishment of the logistics and maintainance technics for supporting the F-106B as a research tocl; a functional check of the lightning instrumentation system; a functional check of the atmospheric chemistry data system; a development of suitable operational procedures; and, a background for projecting improved equipment and operational procedures for future storm hazards programs which will involve storm penetrations. Storm penetration flights are expected to increase the probability of obtaining direct lightning strike data. Some of the planned improvements in equipment and procedures are:

1. Equip the airplane for storm penetration testing (IFR avionics).

2. Have all experimental data systems modified where needed to provide more efficient ground pre- and post-flight servicing.

3. Improve real-time weather and lightning information for making more effective launch decisions and test guidance.

4. For storm penetration research flights, high caliber personnel expertise in the fields of weather radar operation and air traffic control will be required to provide real-time guidance to the flight crew of the NASA F-106B aircraft.

In addition, this paper has documented the characteristics of the NASA F-106B storm research airplane, the direct-strike lightning instrumentation system, atmospheric chemistry data system, and some of the safety considerations and operational procedures that are being used.

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TABLE I.- CHARACTERISTICS OF F-106B AIRCRAFT

Length	21.5 m (70 ft 8 in)
Height	6.17 m (20.25 ft)
Wing span	11.7 m (28 ft 3.5 in)
Wing area (gross)	64.83 m^2 (697.83 ft^2)
Wing chord at root	9.07 m (29 ft 9.25 in)
Aspect ratio	2.198
Wing sweepback angle	60° 6 min 13 sec
Basic weight	116 538 N (26200 lb)
Loaded weight	160 702 N (36129 lb)
Engine	J75-P-17 axial flow turbojet
Thrust at sea level	71 613 N (16100 lb) (military thrust)
Maximum thrust	108 976 N (24500 lb)

TABLE II.- LIGHTNING MEASUREMENTS SENSITIVITIES

Sensor	Measurement	Full-scale direct strike quantity	Sensor output, V	System gain, dB	Full-scale recorded voltage, V
$\dot{I}$	Rate of change of total attachment current to nose boom	10 kA/0.1 μsec	200	-40	2
$\dot{D}$ (nose-mounted)	Rate of change of electric flux density	$\frac{500\ \text{kV/m}}{0.1\ \mu\text{sec}}$[a]	100	-40	1
$\dot{D}$ (tail-mounted)	Rate of change of electric flux density	$\frac{100\ \text{V/m}}{0.1\ \mu\text{sec}}$[b]	0.02	34	1
$\dot{B}$ (both)	Rate of change of magnetic flux density	10 kA/0.1 μsec[c]	100	-40	1

NOTES:

(a) Equivalent to 50 A/m^2

(b) Equivalent to 0.01 A/m^2

(c) Equivalent to 10^4 tesla/sec at 0.5 m distance

TABLE III.- SPECIFICATIONS FOR NASA-WALLOPS SPANDAR RADAR AND C-BAND RADAR

	SPANDAR
Frequency	2700 - 2900 MHz
Peak power output	1 MW
Pulse repetition frequency	320
Beam width	0.4°
Range accuracy	229 m (750 ft)
	C-band
Frequency	5400 - 5900 MHz
Peak power output	1 MW
Azimuth accuracy	0.1 mil
Elevation accuracy	0.1 mil
Range accuracy	±4.57 m (±15 ft) rms (transponder tracking mode)

TABLE IV.- PATUXENT RIVER WSR-57 WEATHER RADAR REFLECTIVITY CHART

Level	Intensity category	Radar color	Maximum reflectivity, dBZ	Rainfall Rate			
				Stratiform		Convective	
				mm/hr	in/hr	mm/hr	in/hr
	No precipitation	White	103.5 dBm at zero range	0.0	0.0	0.0	0.0
1	Weak	Gray	30	2.54	0.1	5.03	0.2
2	Moderate	Black	41	12.7	0.5	27.9	1.1
3	Strong	White	46	25.4	1.0	55.9	2.2
4	Very strong	Gray	50			114.3	4.5
5	Intense	Black	57			180.3	7.1
6	Extreme	White				>180.3	>7.1

TABLE V.- SUMMARY OF FLIGHT CREWS, FLIGHT DURATIONS, AND FUEL USAGE

Date	Type of flight	Pilot	Observer	Flight duration, min	Fuel Usage, Liters	Fuel Usage, Gals
8/23/79	Functional check	G. Keyser	J. Weinig, Maj., (USAF)	55	3360	887
8/28/79	Storm (Yorktown)	G. Keyser	P. Deal	45	2430	642
8/30/79	Functional check	G. Keyser	P. Deal	45	2700	714
9/03/79	Storm (Crisfield)	G. Keyser	P. Deal	55	2960	783
9/11/79	Functional check	G. Keyser	P. Deal	55	3190	844
9/14/79	Storm	G. Keyser	P. Deal	50	3070	812
9/18/79	Pilot familiarization and electromagnetic interference	P. Deal	G. Keyser	55	3300	871
9/19/79	Pilot familiarization and observer checkout	G. Keyser	B. Fisher	50	2710	717

TABLE V.- CONCLUDED

Date	Type of flight	Pilot	Observer	Flight duration, min	Fuel Usage, Liters	Fuel Usage, Gals
9/22/79	Storm	G. Keyser	B. Fisher	55	2880	762
9/26/79	Pilot familiarization, airspeed calibration, photo chase	P. Deal	G. Keyser	70	3710	979
9/27/79	Pilot familiarization, airspeed calibration	G. Keyser	M. Klebitz	55	2760	729
9/27/79	Pilot familiarization and observer checkout	P. Deal	N. Crabill	50	3150	833
9/28/79	Pilot familiarization and movie documentation	P. Deal	J. Patton	65	3570	943
9/28/79	Storm	P. Deal	L. Bynes	60	3040	802
10/2/79	Pilot familiarization	P. Deal	C. Chandler	65	3160	835
15 flights				13 hrs: 50 min		

TABLE VI.- WEAPONS BAY TEMPERATURE READINGS

Altitude		Temperature, $^{\circ}F$	
m	ft	Forward	A ft
0	0	80	80
3,048	10,000	85	90
5,486	18,000	85	90
9,144	30,000	90	95
12,192	40,000	80	95
13,716	45,000	80	90
610	2,000	80	105
0	0	95	115

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22. August 28, 1979. Yorktown storm area showing aircraft ground track from C-band radar and WSR-57 precipitation contour and visual lightning events.

23. Patuxent River WSR-57 telephone facsimile plot for September 3, 1979, 18:50 GMT. Weather bulletin written on screen at 18:35 GMT. Crisfield storm. (Facsimile plot magnified 1.6 times for publication.)

24. September 3, 1979. Crisfield storm area showing aircraft ground track from C-band radar, WSR-57 precipitation and visual lightning events.

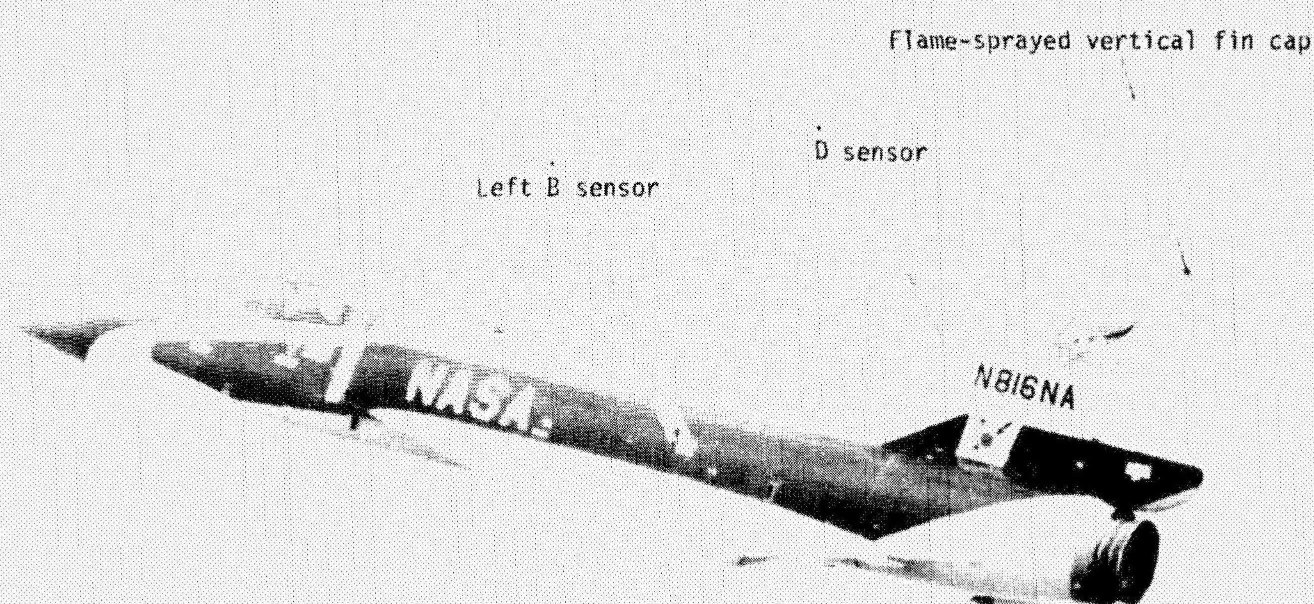

Figure 1.- F-106B test aircraft.

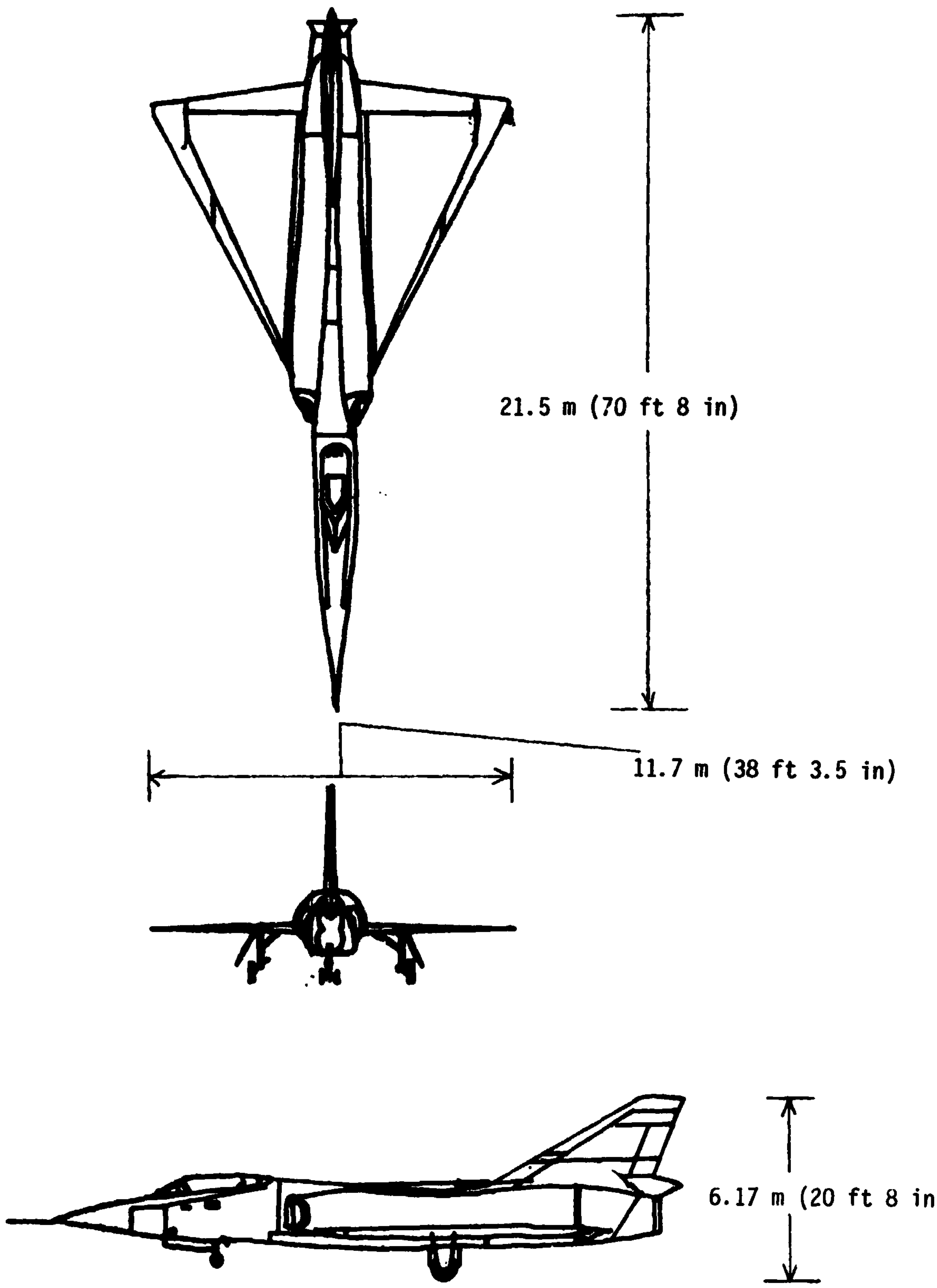

Figure 2.-Dimensioned three-view of F-106B aircraft.

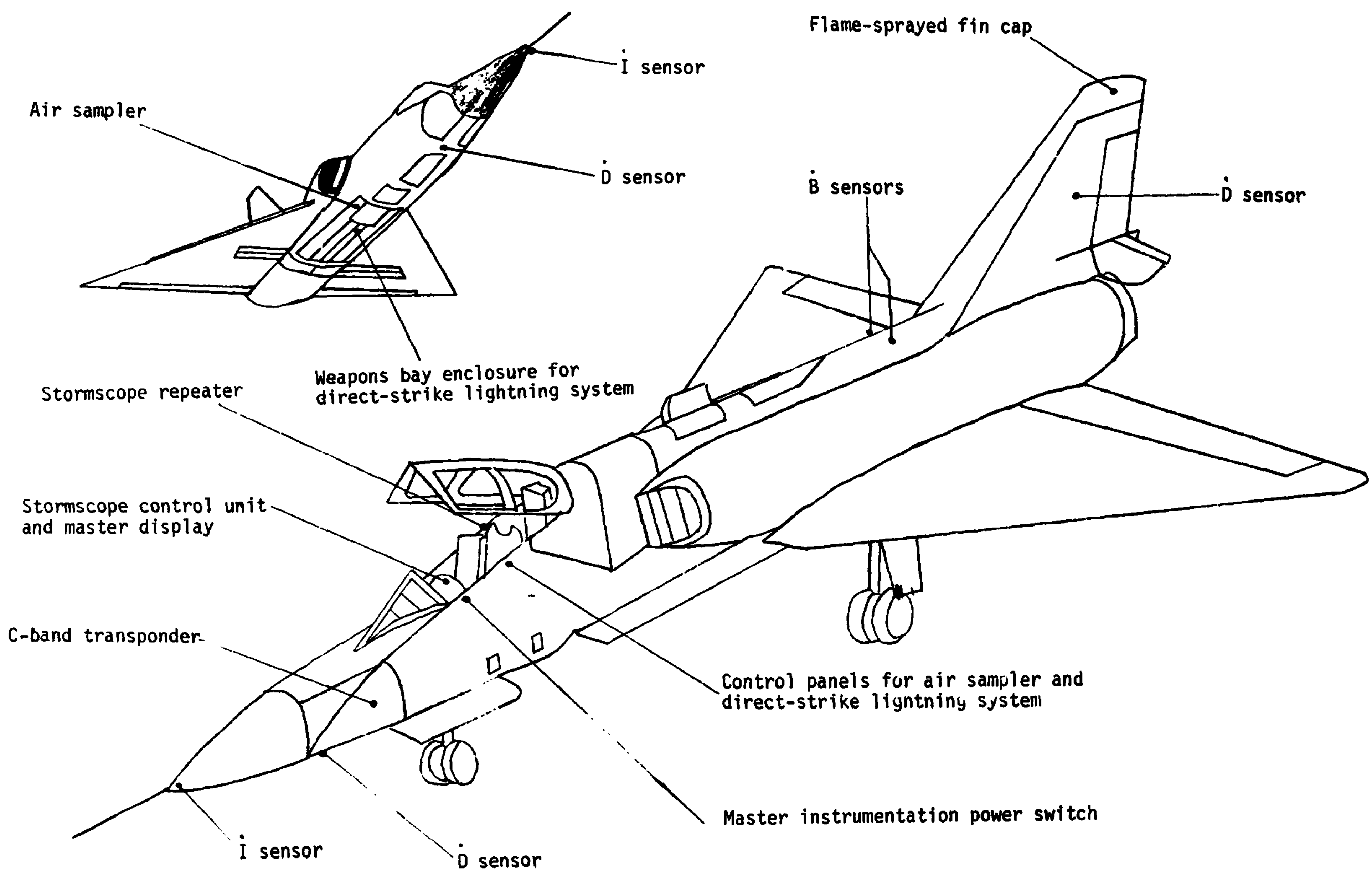

Figure 3.- Sensors location on NASA F-106B aircraft for Storm Hazards '79 Program.

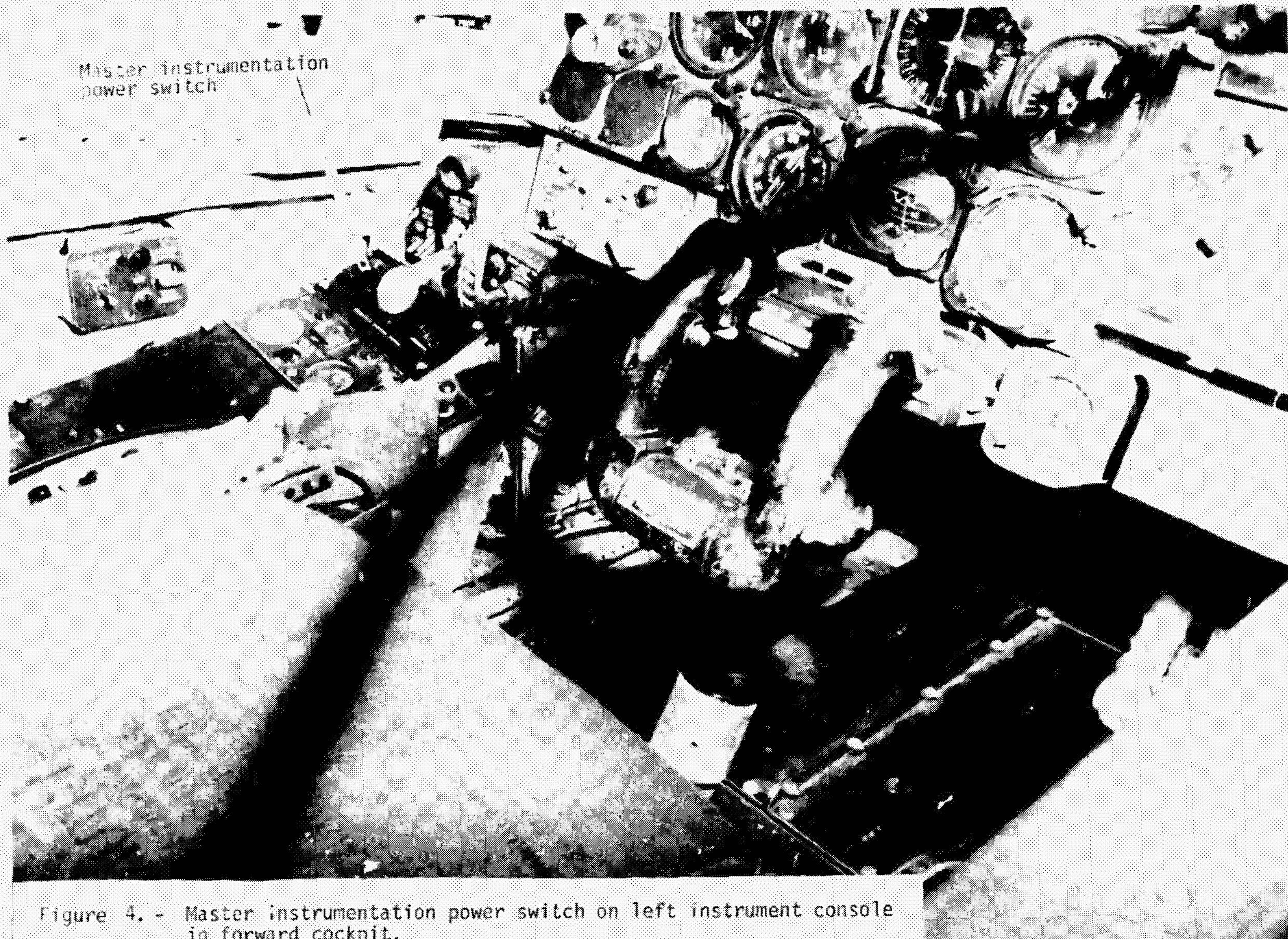

Figure 4. - Master instrumentation power switch on left instrument console in forward cockpit.

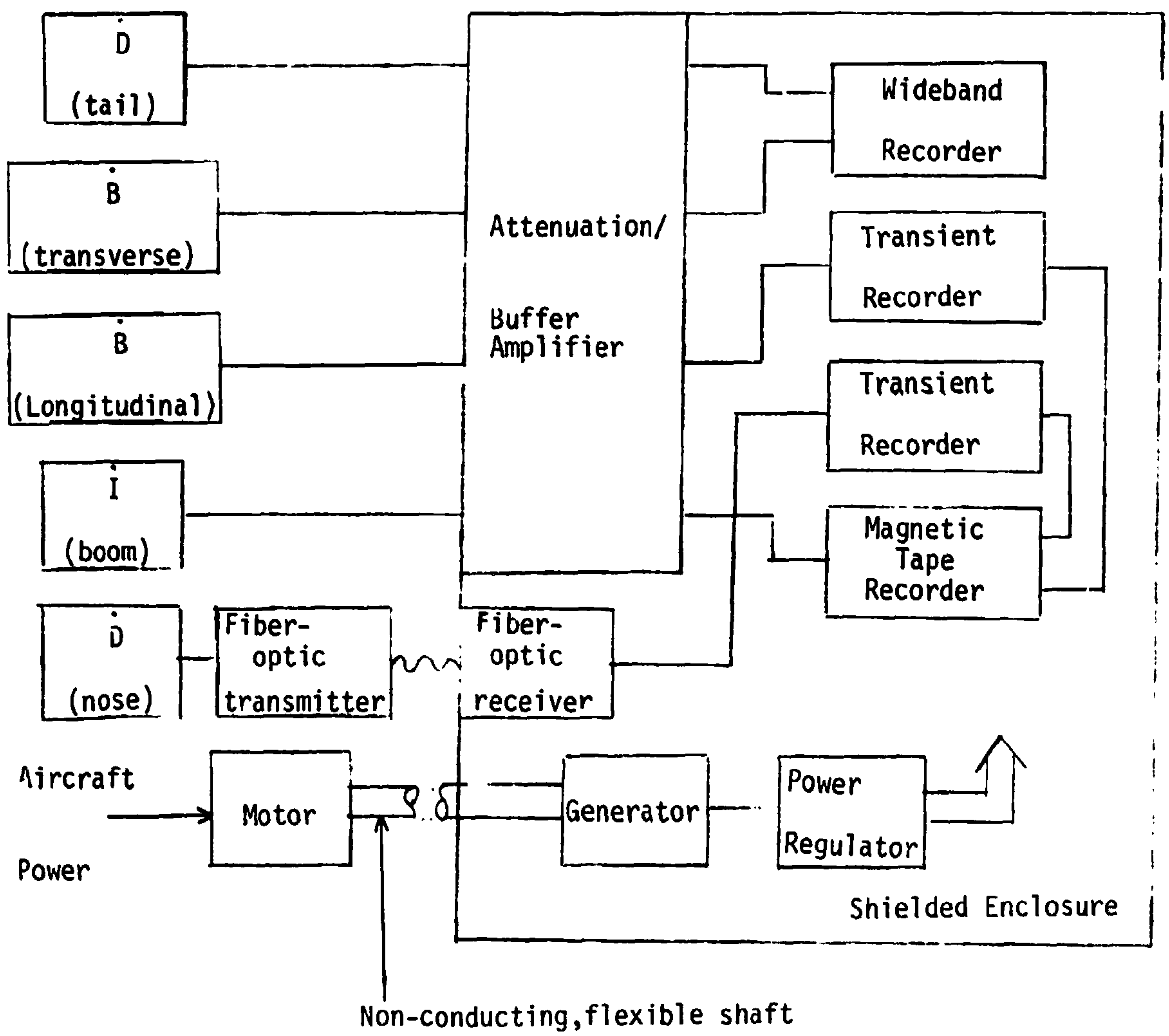

Figure 5.- Lightning instrumentation system block diagram.

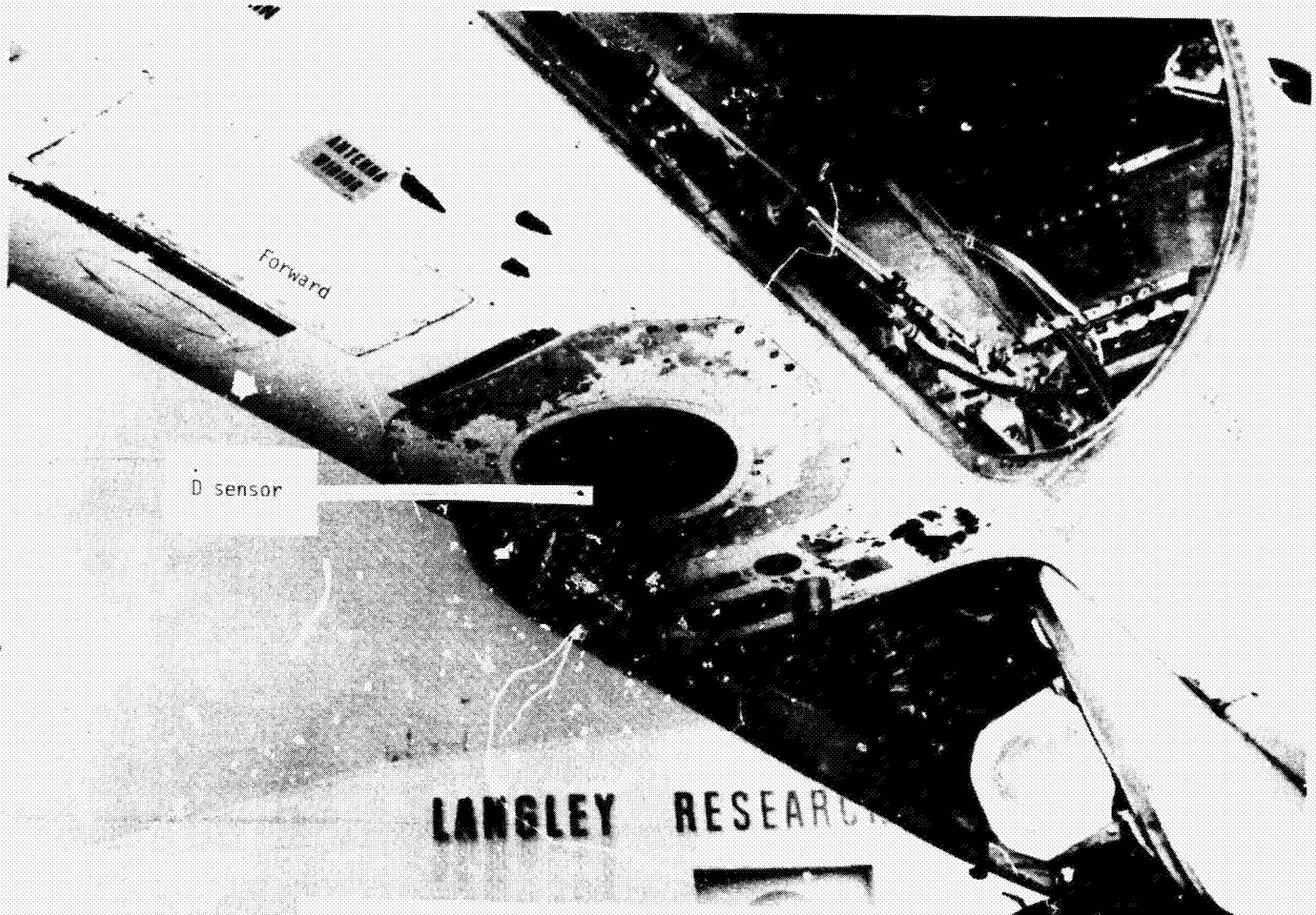

Figure 7.- Nose-mounted D sensor on test aircraft.

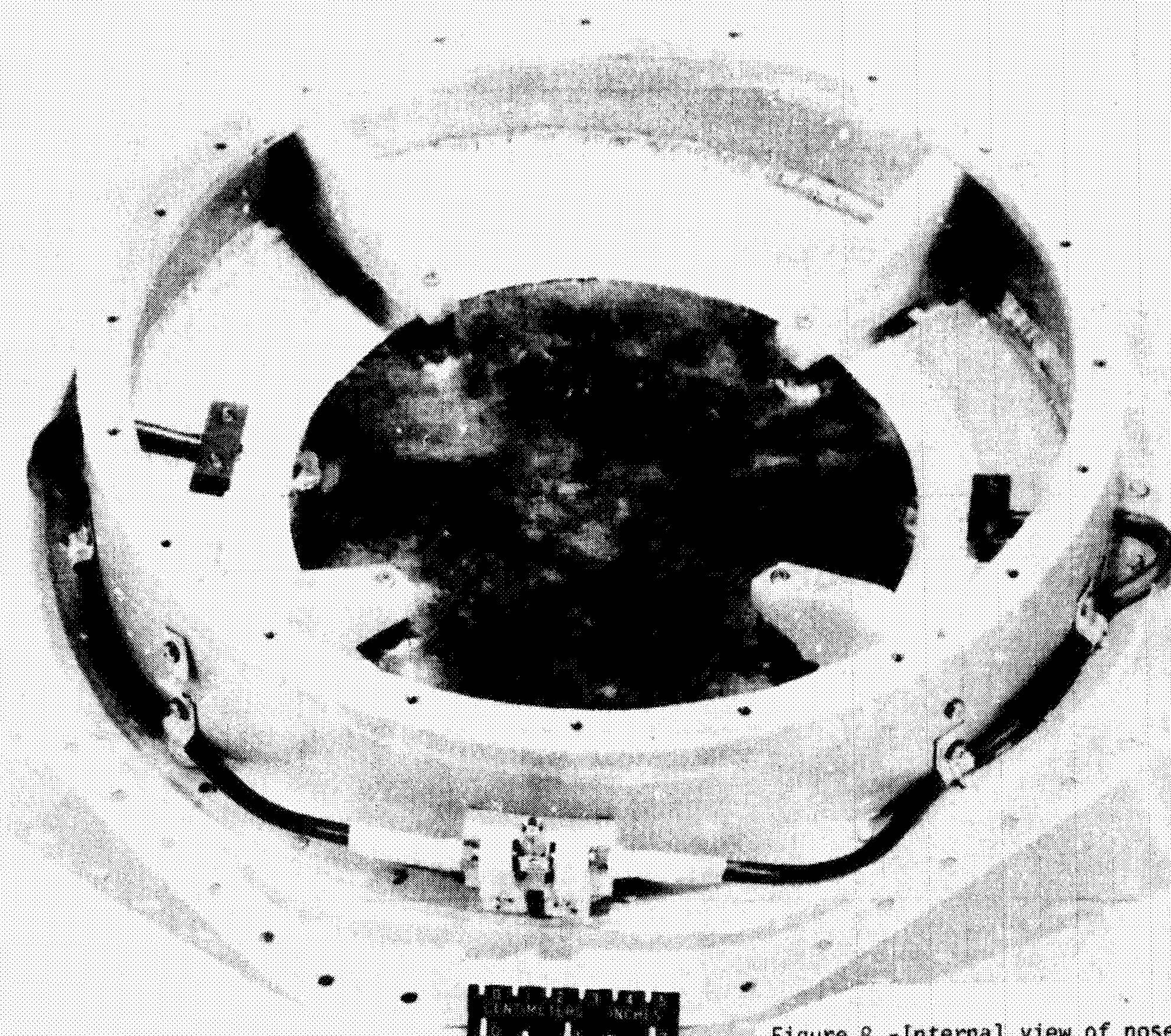

Figure 8.-Internal view of nose-mounted $\dot{D}$ sensor.

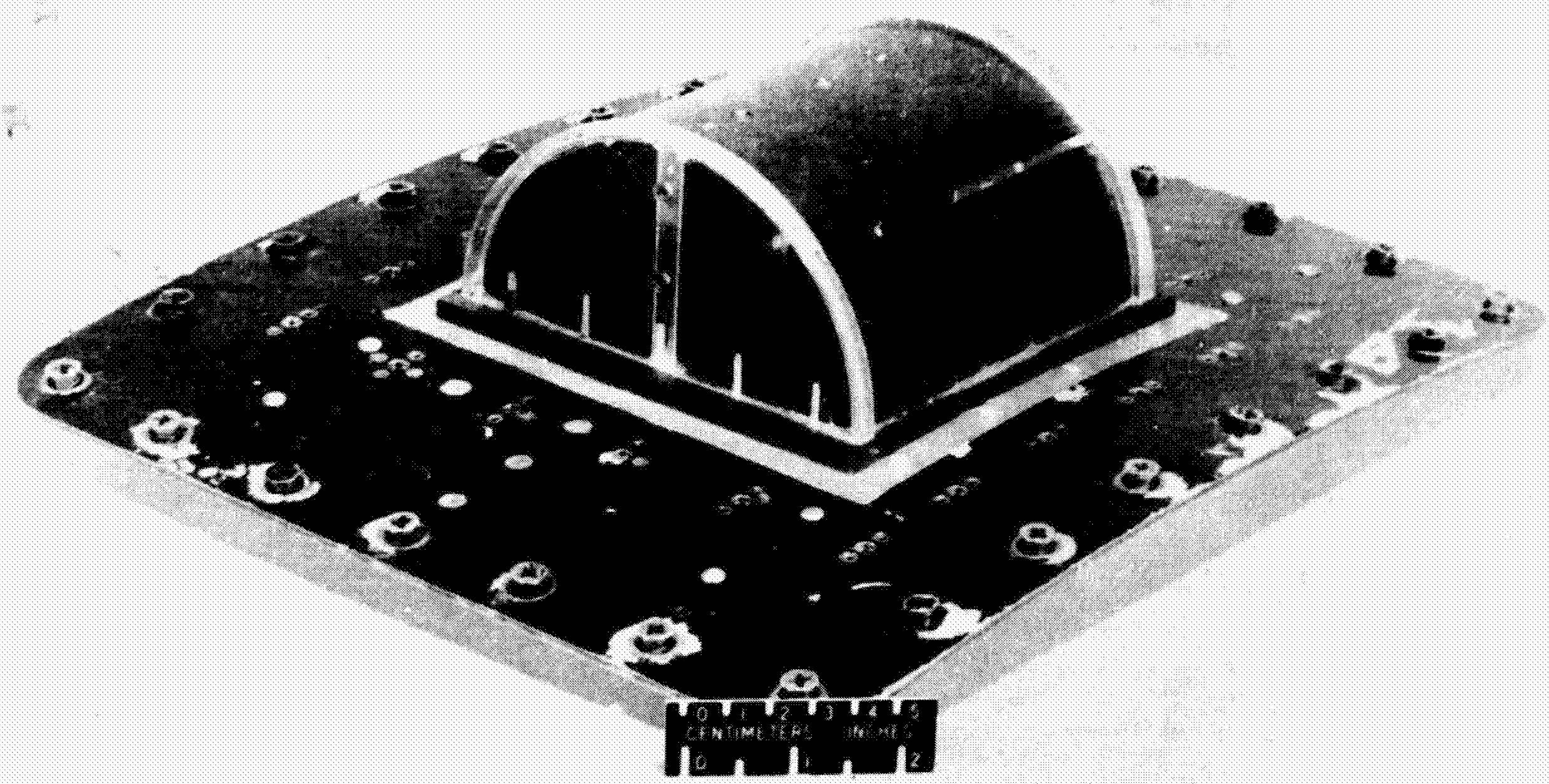

Figure 9.- $\dot{B}$ sensor mounted on aircraft mounting plate.

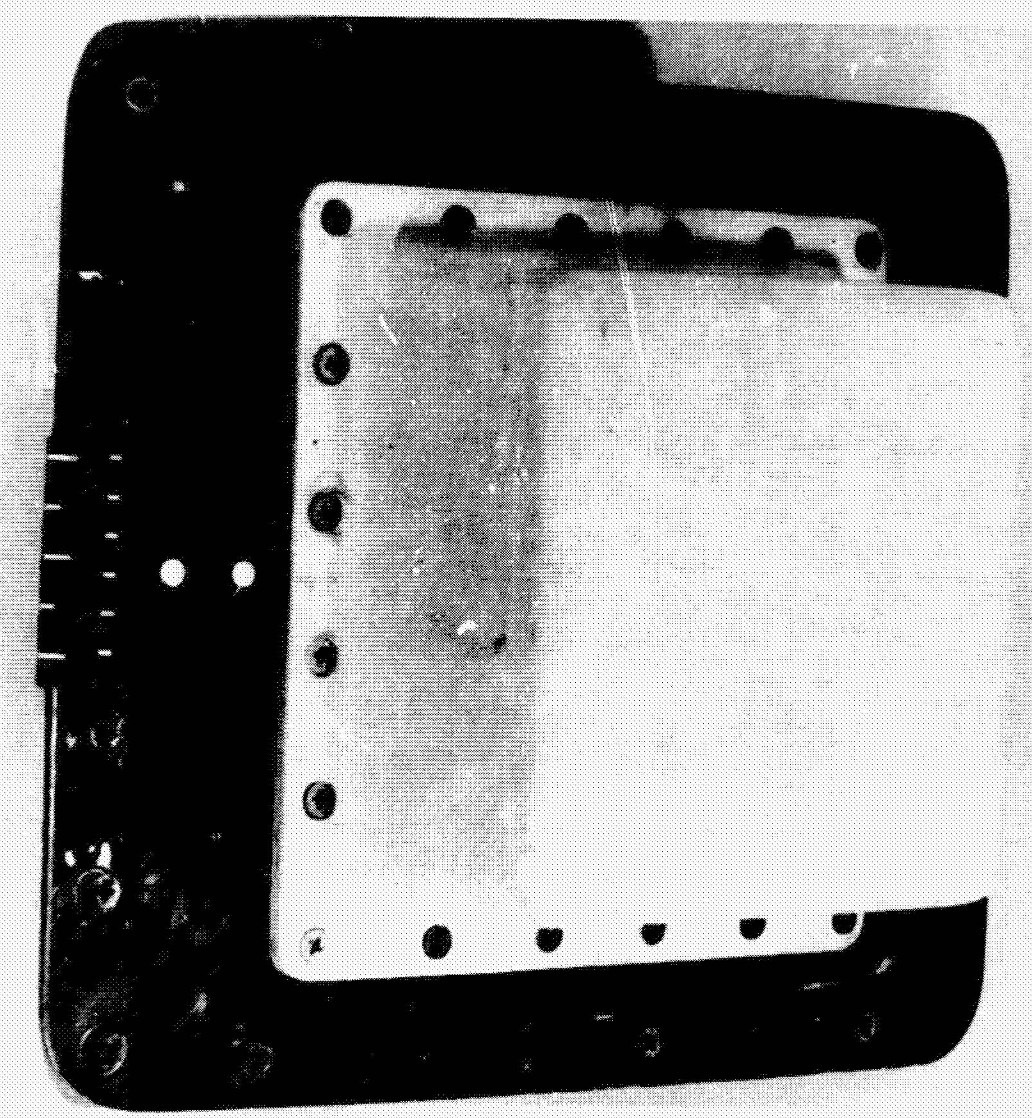

Figure 10.- $\dot{B}$ sensor with fiberglass cover attached.

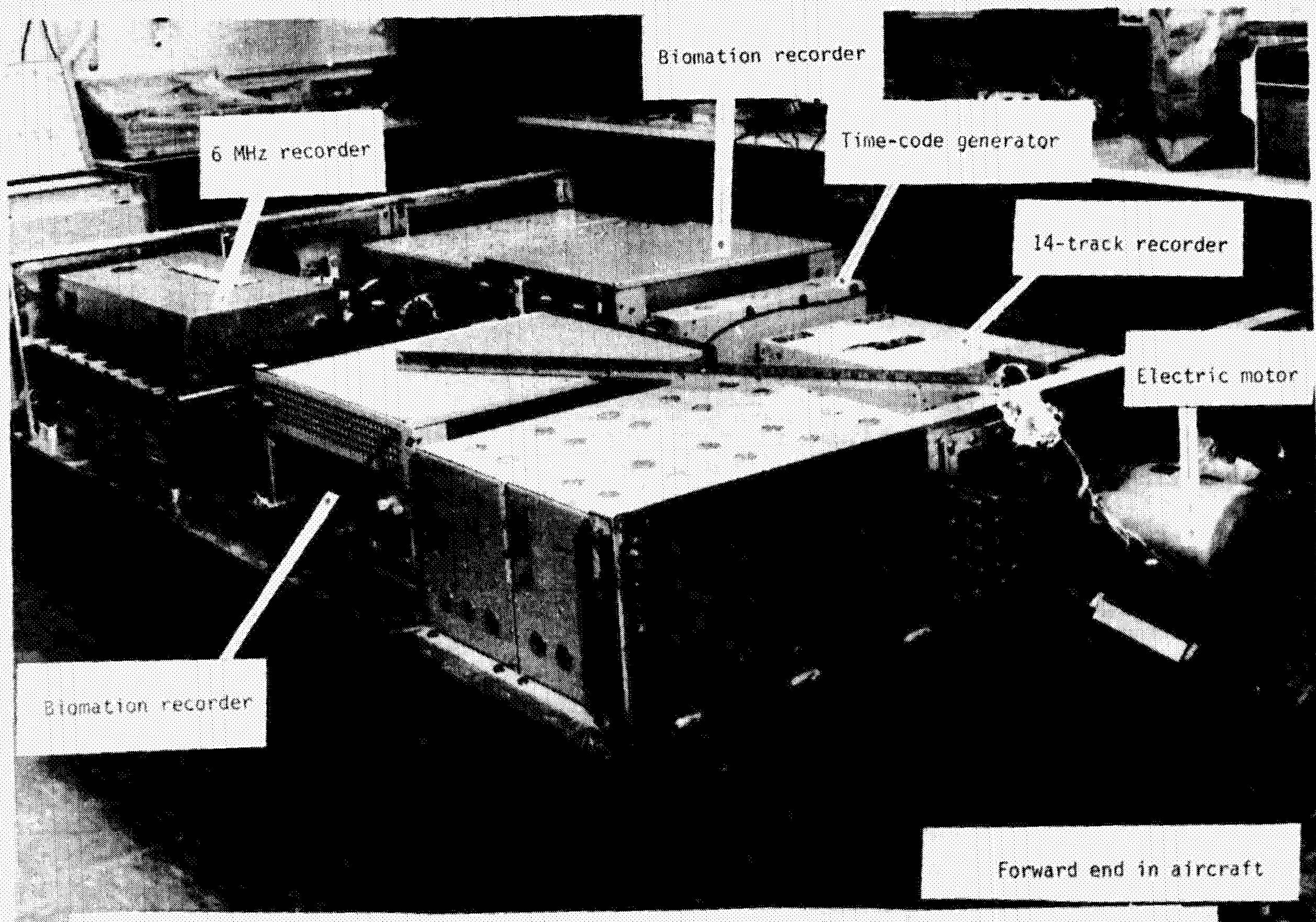

Figure 11.- Direct-strike lightning recording system for mounting in weapons bay enclosure. Cover has been removed to show internal components.

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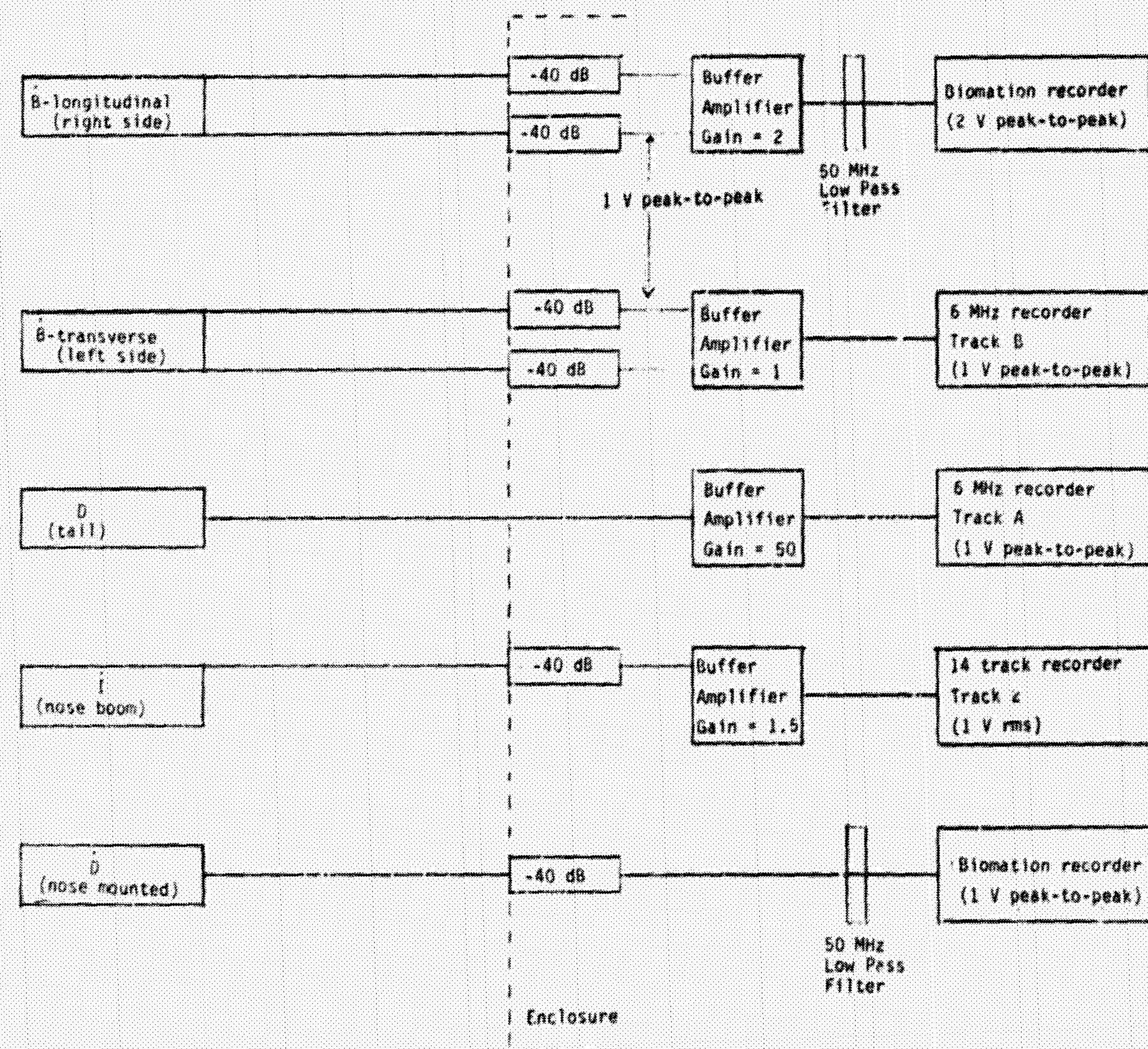

(b) Flight of September 22, 1979.

Figure 12.- Concluded.

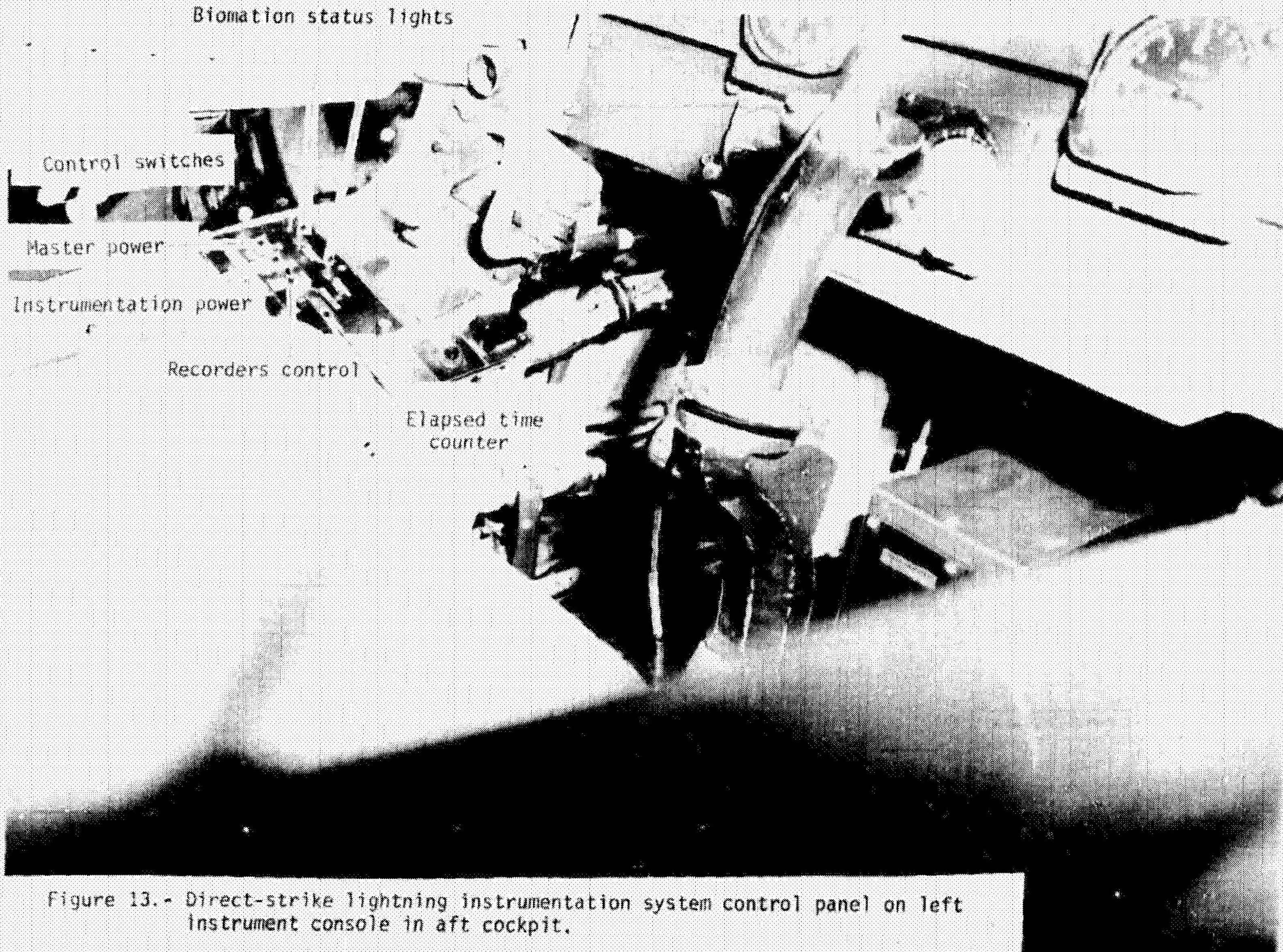

Figure 13.- Direct-strike lightning instrumentation system control panel on left instrument console in aft cockpit.

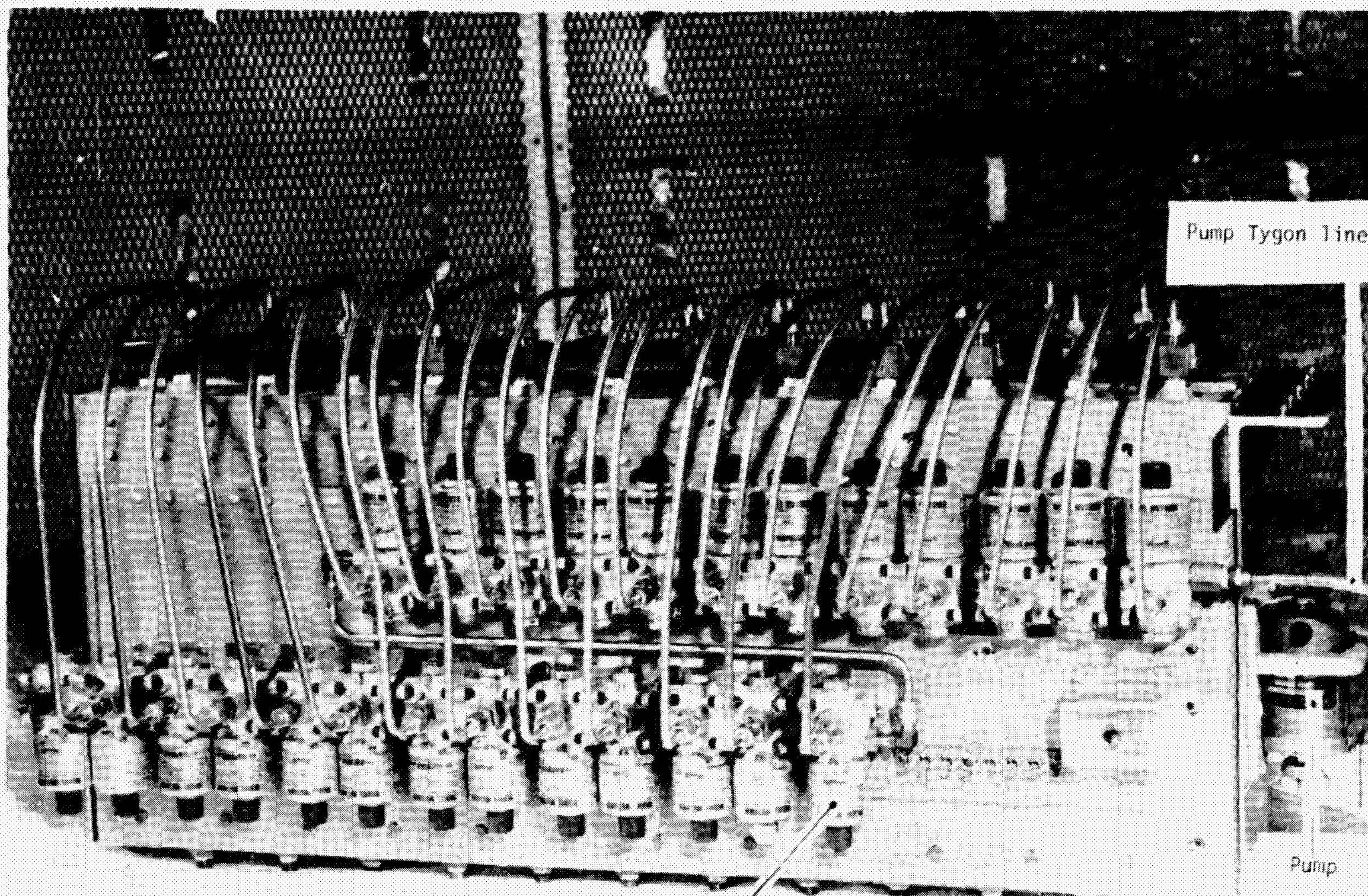

Figure 14.-Air sampler system for atmospheric chemistry experiment. Side view.

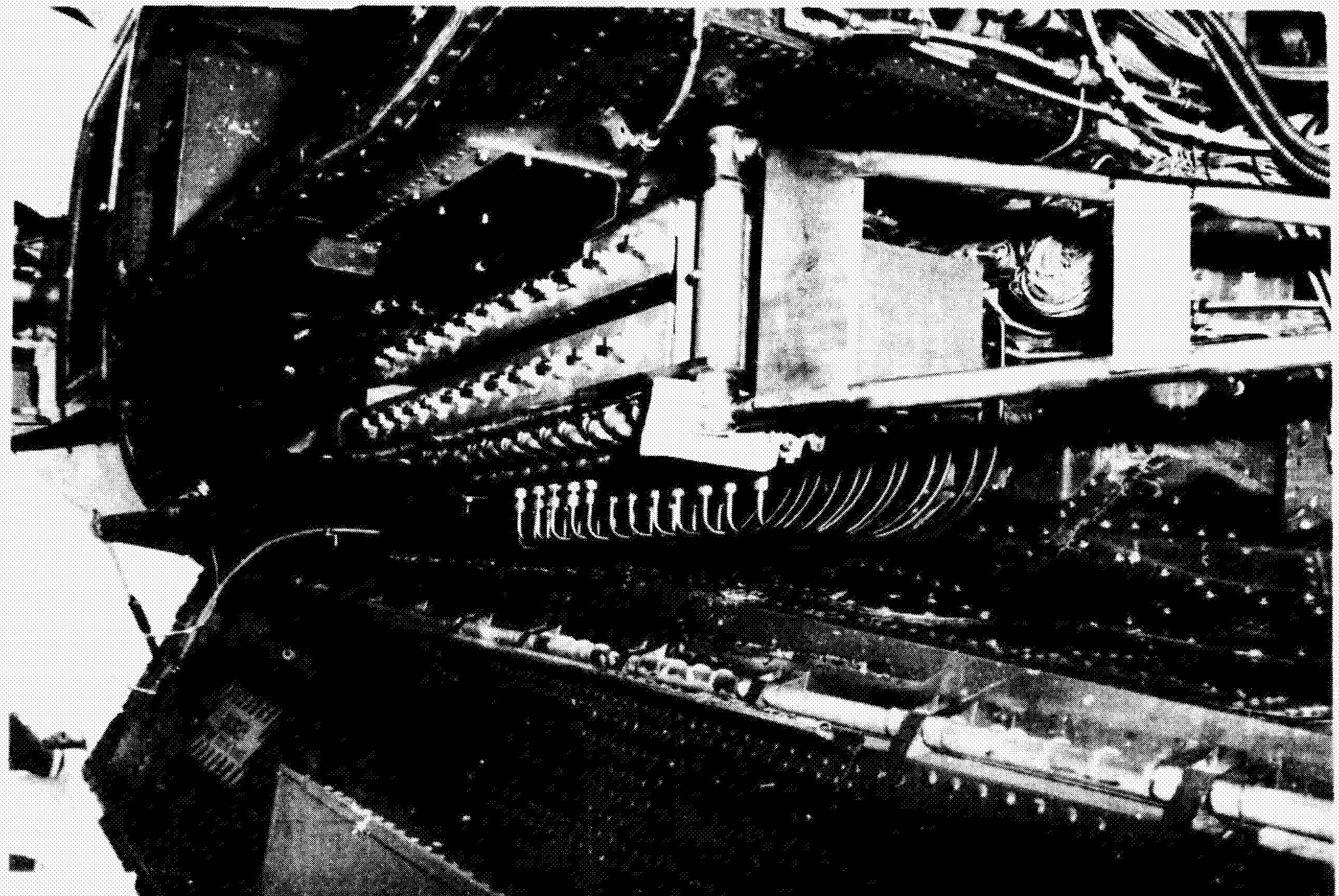

Figure 15.- Air sampler system for atmospheric chemistry experiment mounted in aircraft weapons bay. View looking forward.

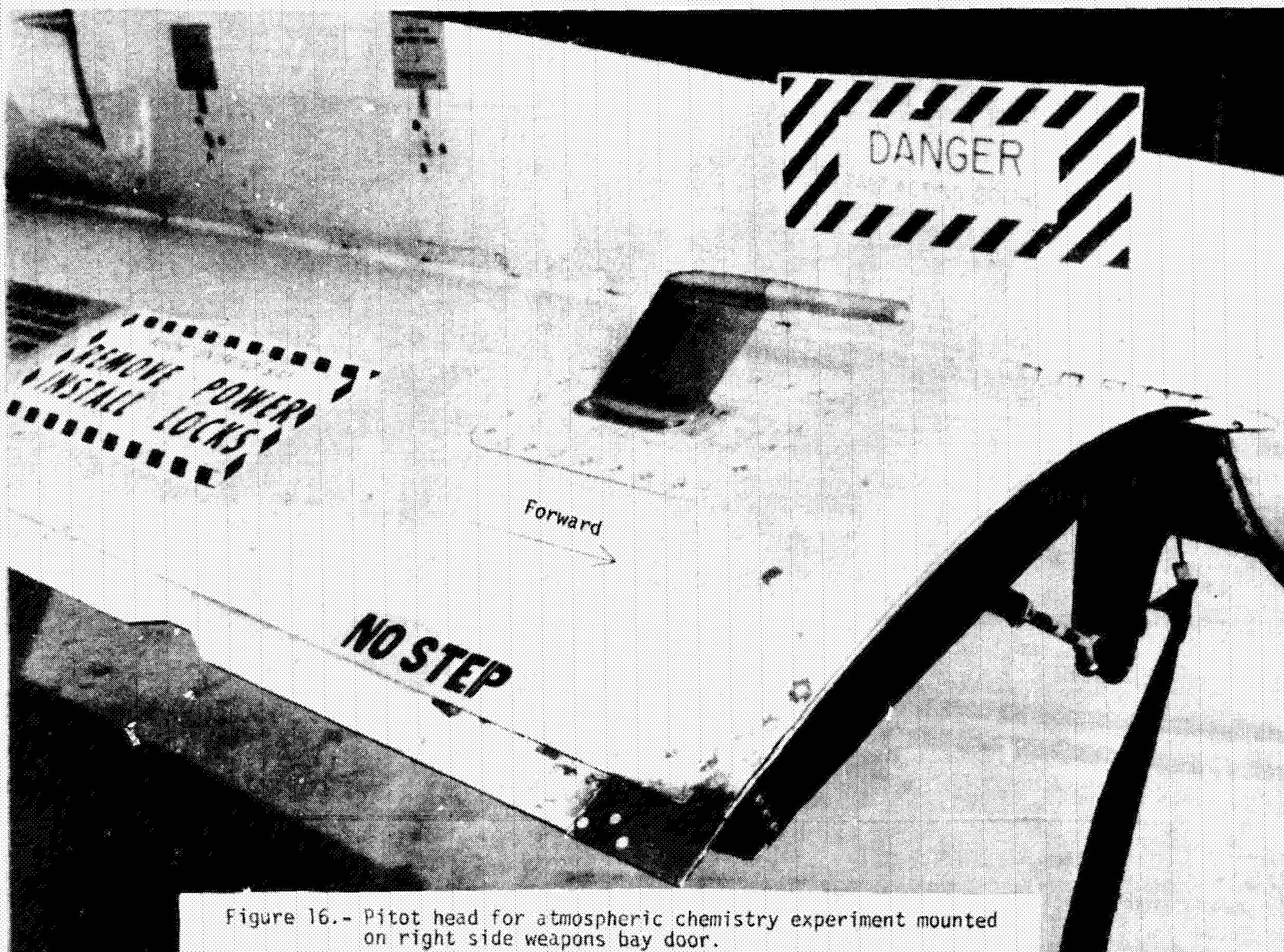

Figure 16.- Pitot head for atmospheric chemistry experiment mounted on right side weapons bay door.

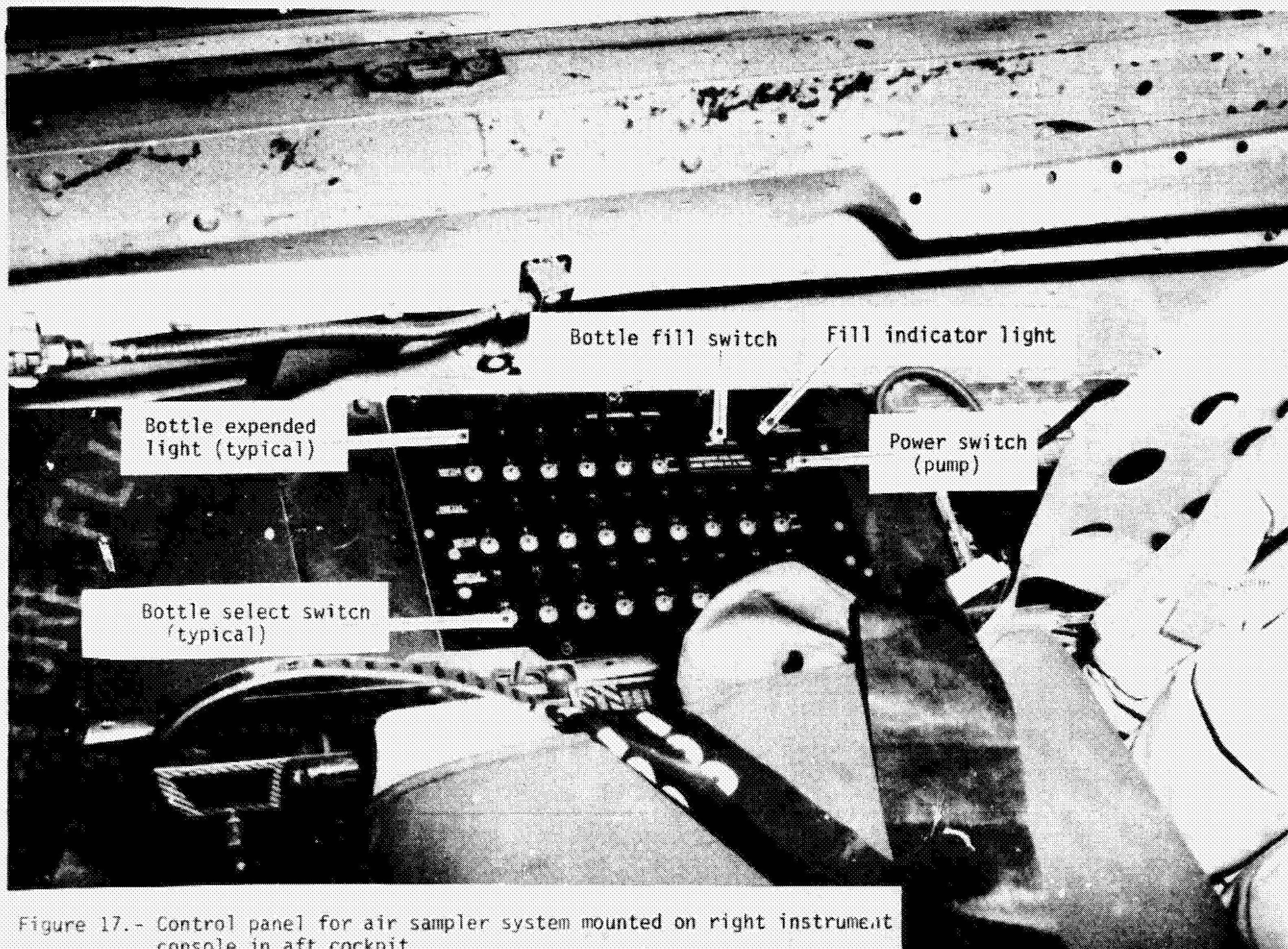

Figure 17.- Control panel for air sampler system mounted on right instrument console in aft cockpit.

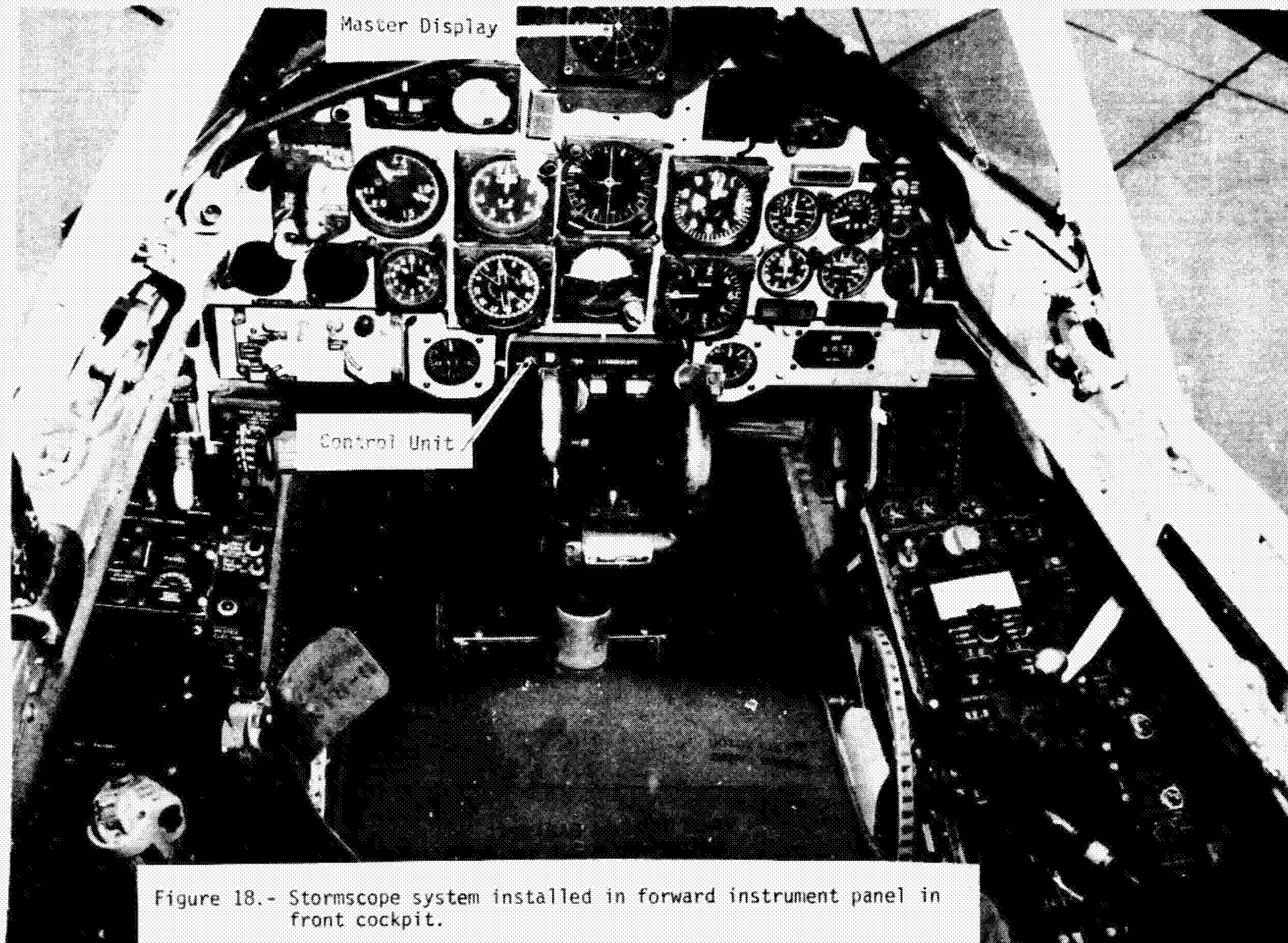

Figure 18.- Stormscope system installed in forward instrument panel in front cockpit.

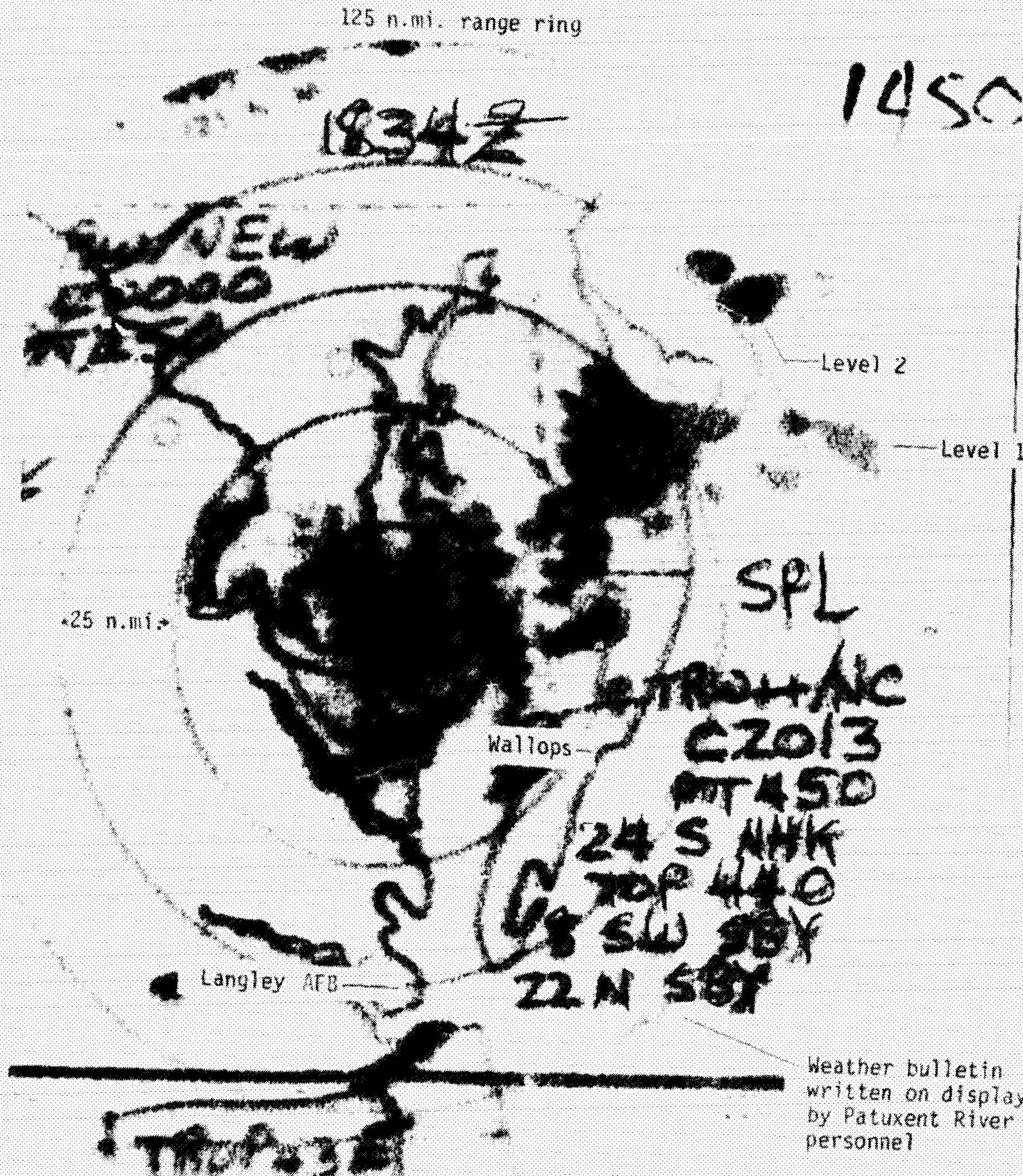

Figure 19.- Sample Patuxent River WSR-57 radar facsimile. Received at Langley at 14:50 EDT, August 28, 1979. (Facsimile plot magnified 1.6 times for publication.)

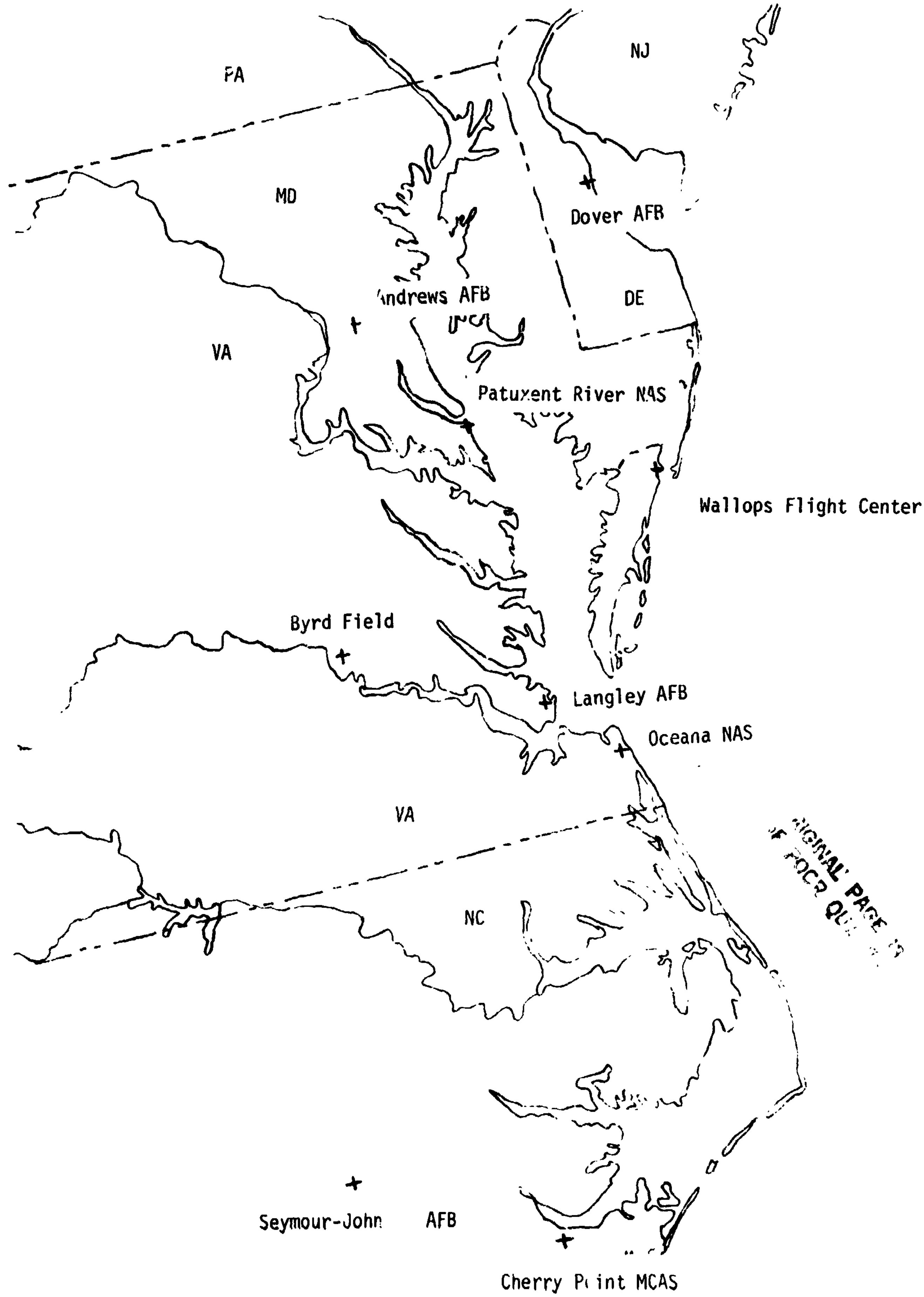

Figure 20.- Diversionary fields used in Storm Hazards '79 Program.

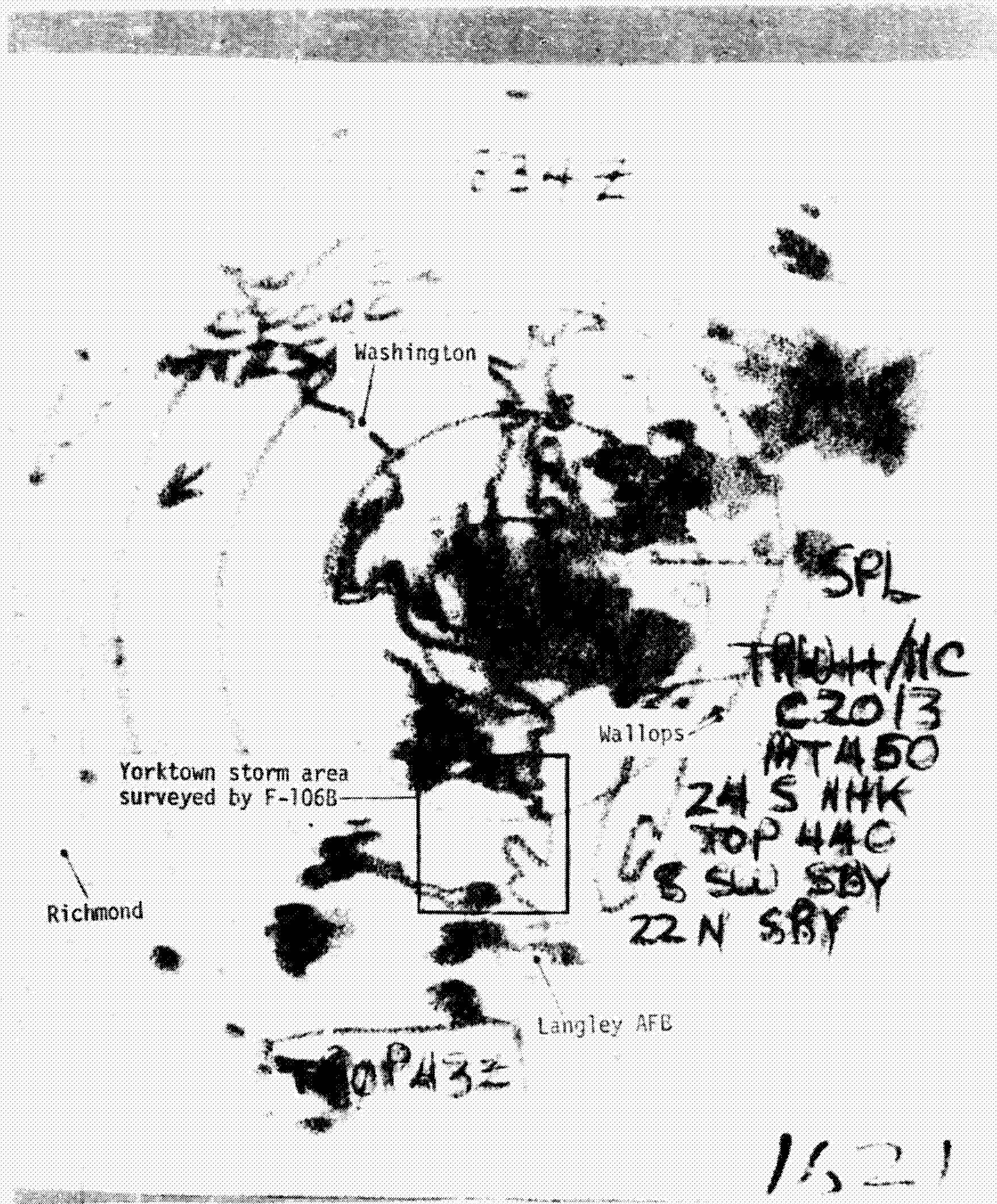

Figure 21.- Patuxent River WSR-57 telephone facsimile plot for August 28, 1979, 20:21 GMT. Weather bulletin written on screen at 18:34 GMT, Yorktown storm. (Facsimile plot magnified 1.6 times for publication.)

Key

Aircraft position	Altitude, m	Altitude, ft	Time, GMT		
a	5428	17 808	20	46	13
b	4150	13 615	20	51	13
c	3783	12 411	20	56	13
d	4855	15 928	21	04	13
e	2014	6 608	21	09	13
f	3593	11 788	21	11	59

◊ Lightning event at 20:54

□ Lightning event at 20:58

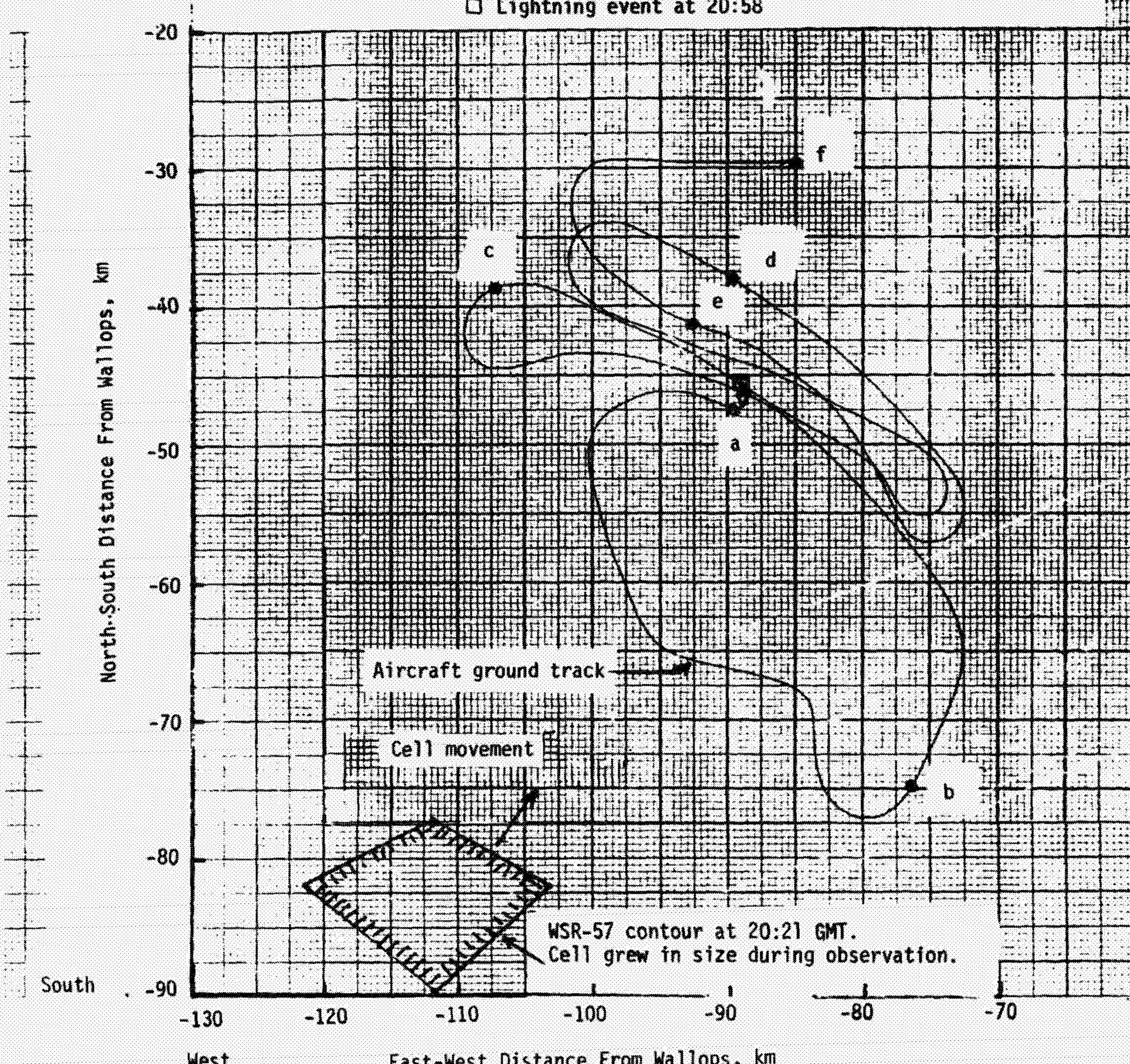

Figure 22.- August 28, 1979. Yorktown storm area showing aircraft ground track from C-band radar and WSR-57 precipitation contour and visual lightning events.

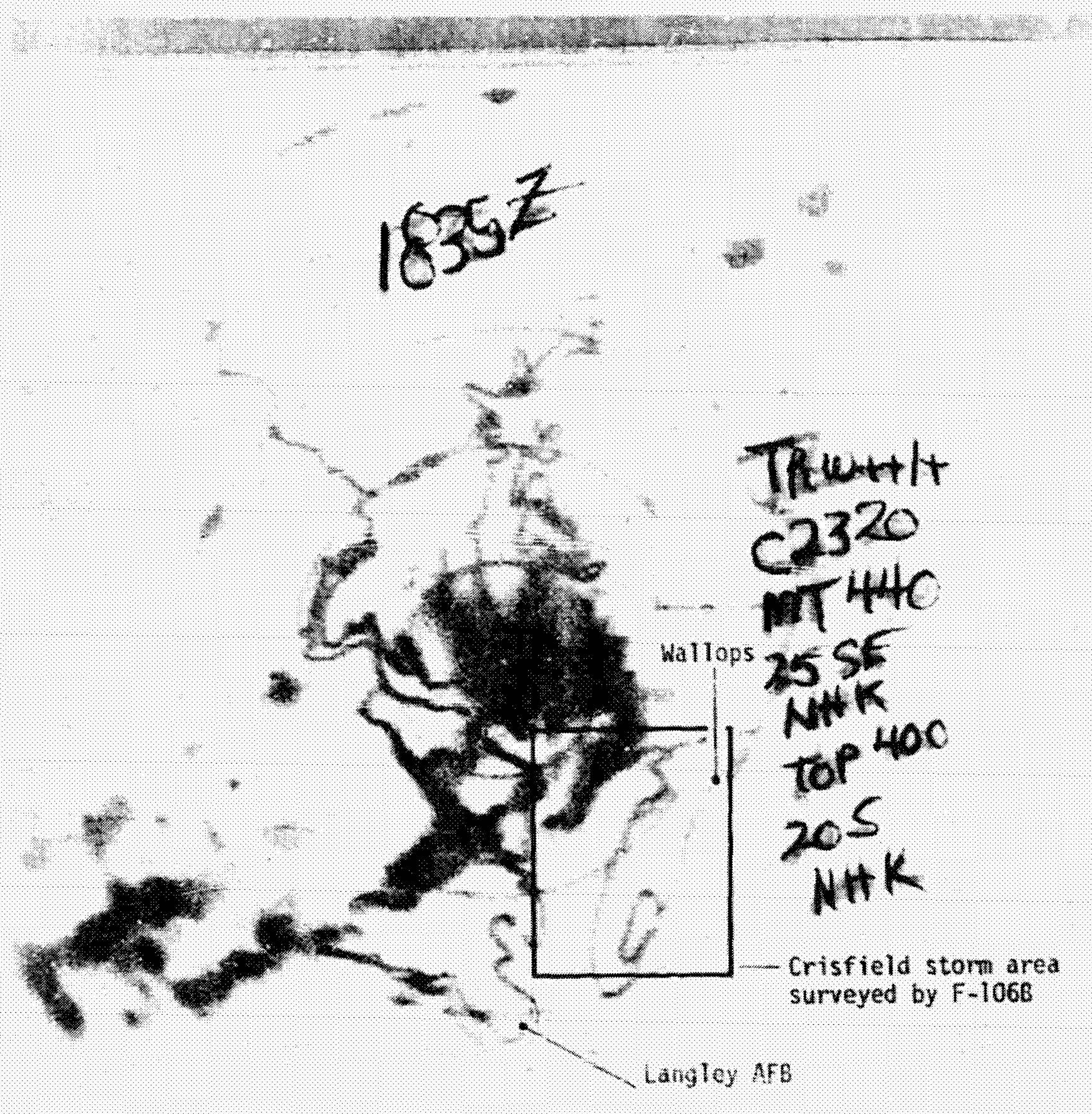

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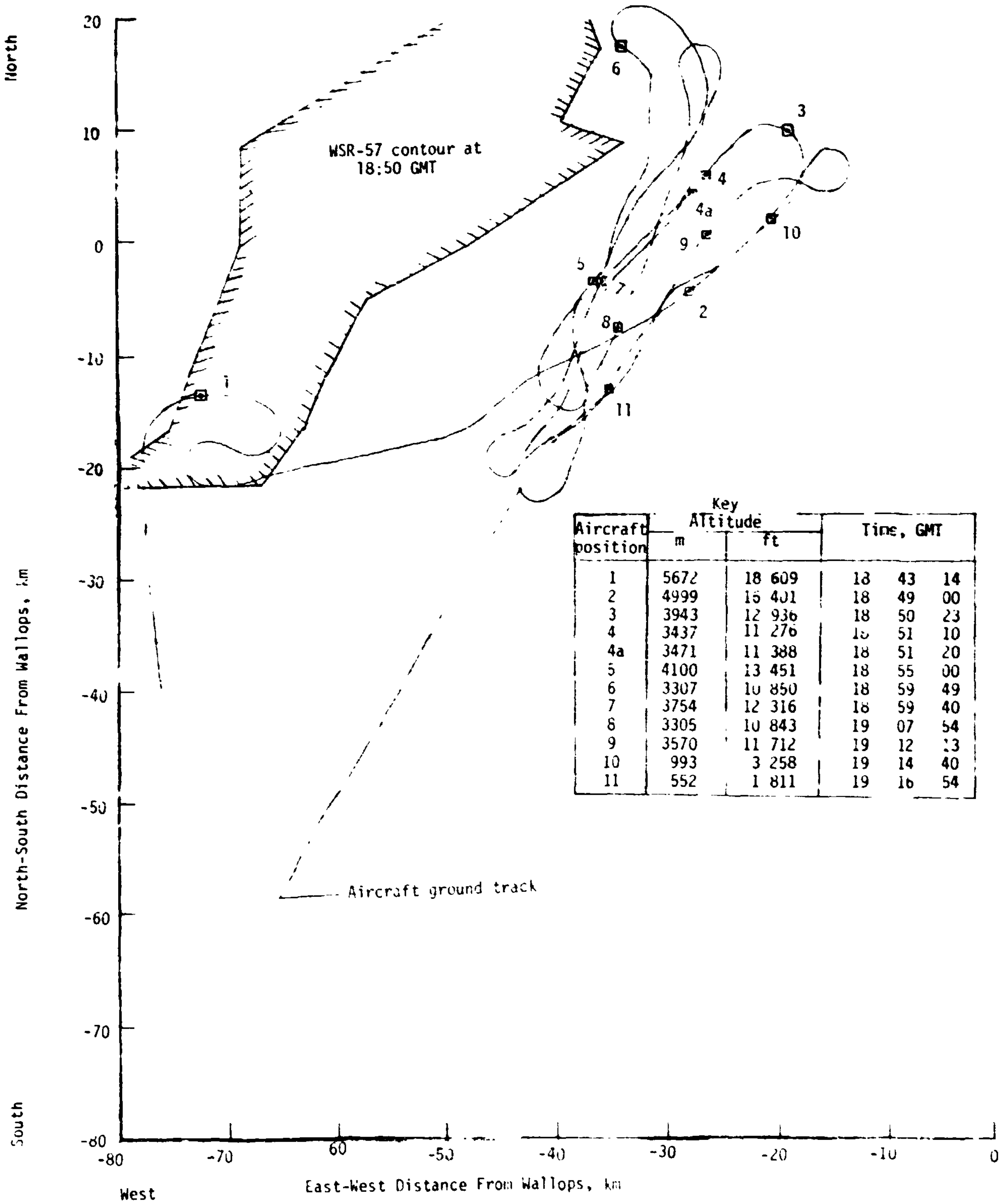
Figure 23.- Patuxent River WSR-57 telephone facsimile plot for September 3, 1979, 18:50 GMT. Weather bulletin written on screen at 18:35 GMT. Crisfield storm. (Facsimile plot magnified 1.6 times for publication.)



Key

Aircraft position	Altitude, m	Altitude, ft	Time, GMT		
1	5672	18 609	18	43	14
2	4999	16 401	18	49	00
3	3943	12 936	18	50	23
4	3437	11 276	18	51	10
4a	3471	11 388	18	51	20
5	4100	13 451	18	55	00
6	3307	10 850	18	59	49
7	3754	12 316	18	59	40
8	3305	10 843	19	07	54
9	3570	11 712	19	12	13
10	993	3 258	19	14	40
11	552	1 811	19	16	54

Figure 24.- September 3, 1979. Crisfield storm area showing aircraft ground track from C-band radar, WSR-57 precipitation contour and visual lightning events.

ADDENDUM

Subsequent to the final typing of this report, another source of radar reflectivity data became available for the Yorktown and Crisfield storms. These data provide suf. :iently improved information, compared to that given in the text by the Patuxent River WSR-57 radar facsimile plots, that they are provided and discussed in this addendum

For the Yorktown and Crisfield storms discussed in the text, the NASA-Wallops SPANDAR radar sampled precipitation intensity (reflectivity) to a maximum range of approximately 75 n.mi. The raw radar video data were digitized and converted to "received power" and "rainfall rate" using the radar equations. Rainfall rate was then corrected for range to give reflectivity in dBZ. For the plots presented in this addendum, the reflectivity values were computer averaged over surfaces of 1 km^2 and then plotted at the centers of each averaged area to the nearest 5 dBZ. The NASA-Wallops SPANDAR radar was the origin of the axis system. Finally, the computer plots were faired manually to produce contours of constant reflectivity. Details on the SPANDAR radar system and radar computations may be found in NASA CR-2592, "Radar Derived Spatial Statistics of Summer Rain; Volume II - Data Reduction and Analysis," by Konrad and Krepfli.

The SPANDAR reflectivity data for the Yorktown storm of August 28, 1979, are shown for two times, 20:55:19 and 21:13:10 GMT, in figures i and ii, respectively. These figures accompany the presentation given in figure 22. As was the case for figure 22, the aircraft ground track from the NASA-Wallops C-band radar has been superimposed to scale. Care should be taken when comparing figure 22 to figures i and ii in that figure 22 is plotted in kilometers while the latter two figures are plotted in nautical miles. The general motion of the storm from southwest to northeast can be seen by comparing the relative positions of the aircraft ground track to the radar contours in figures 22, i, and ii. In the 17 minutes and 51 seconds which elapsed between figures i and ii, the southern portion of the storm dissipated. It can be seen in figures i and ii that the aircraft was flying ahead of the storm in the vicinity of the most intense portions of the storm, having a reflectivity of 35 to 40 dBZ. The peak reflectivity from the WSR-57 radar at 20:21 GMT was 31 to 40 dBZ (figure 22).

During the flight, the NASA-Wallops SPANDAR radar sampled data at a tilt angle of 0°. Considering the curvature of the earth, this meant that the approximate altitudes of the centers of the reflectivity contours in figures i and ii were 0.5 n.mi. The average aircraft altitude was about 2 n.mi., however. This difference in altitudes made it appear that the aircraft was making thunderstorm penetrations, while in actuality, the aircraft was maneuvering outside the clouds in regions of clear air at a higher elevation. The WSR-57 radar tilt angle was 0.5°, which meant that the approximate altitude of the center of the radar contour in figure 22 was approximately 1 n.mi.

The SPANDAR reflectivity data at 18:50:00 GMT for the Crisfield storm on September 3, 1979, are shown in figure iii. As in figures i and ii, the aircraft ground track has been superimposed to scale, and the data are plotted in nautical miles. The data in figure iii correspond to the WSR-57 contour data shown in figure 24. The peak reflectivity shown in figure iii, 40 to 45 dBZ, is in agreement with the 31 to 40 dBZ detected by the WSR-57 radar (figure 24). The difference in reflectivity contour shapes in figures iii and 24 is due in part to poor resolution of the WSR-57 radar facsimiles received at NASA-Langley as well as to the difference in altitude being surveyed. As was the case for the Yorktown storm, the F-106B test aircraft was flying at a higher altitude than that at which the SPANDAR reflectivity contour was made. The average aircraft altitude during the mission was 1.8 n.mi., while the approximate height of the center of the SPANDAR contour in figure iii was 0.13 n.mi.

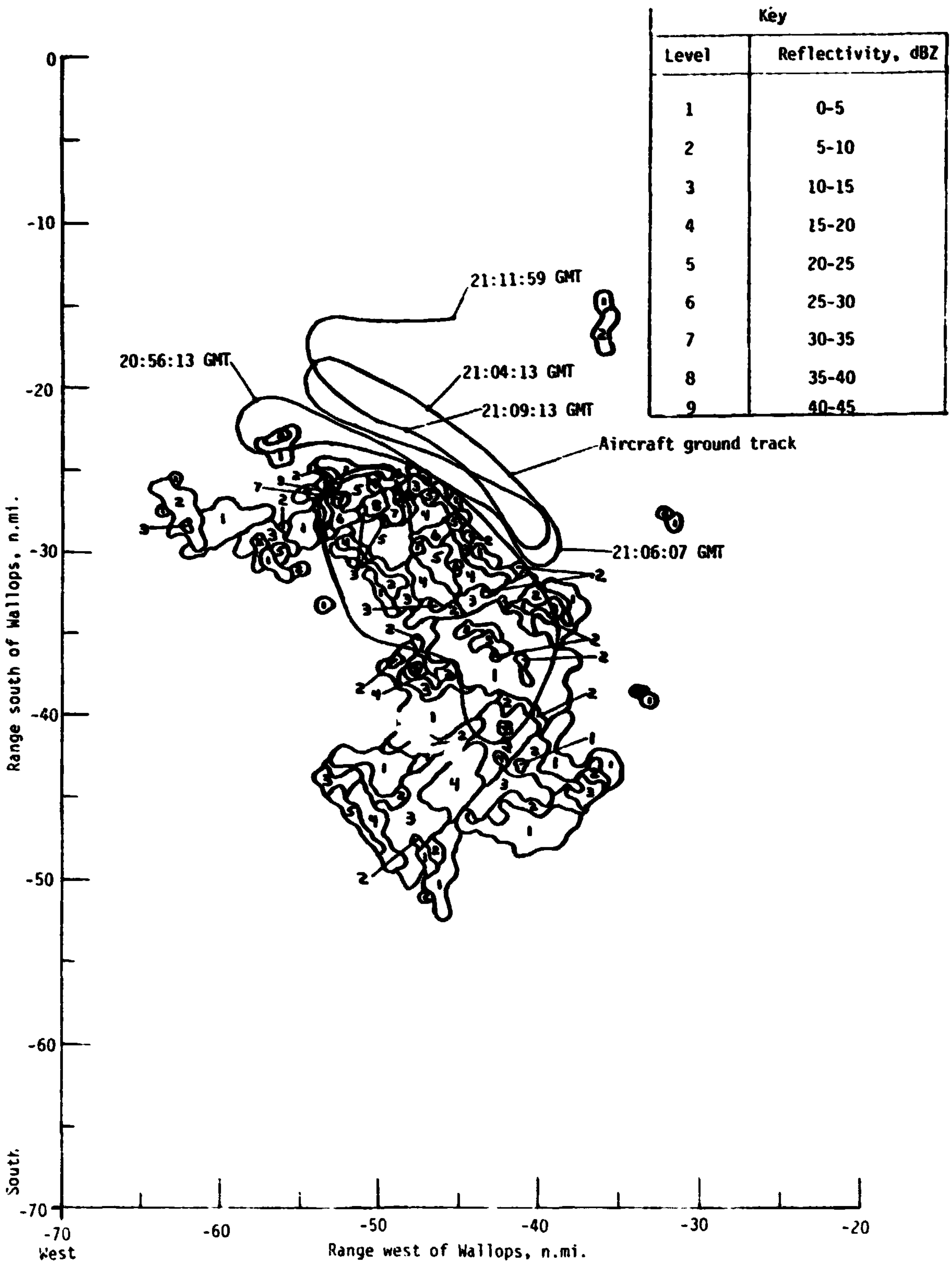


Figure i.- SPANDAR reflectivity levels at 20:55:19 GMT and aircraft ground track from C-band radar for Yorktown storm (August 28, 1979).

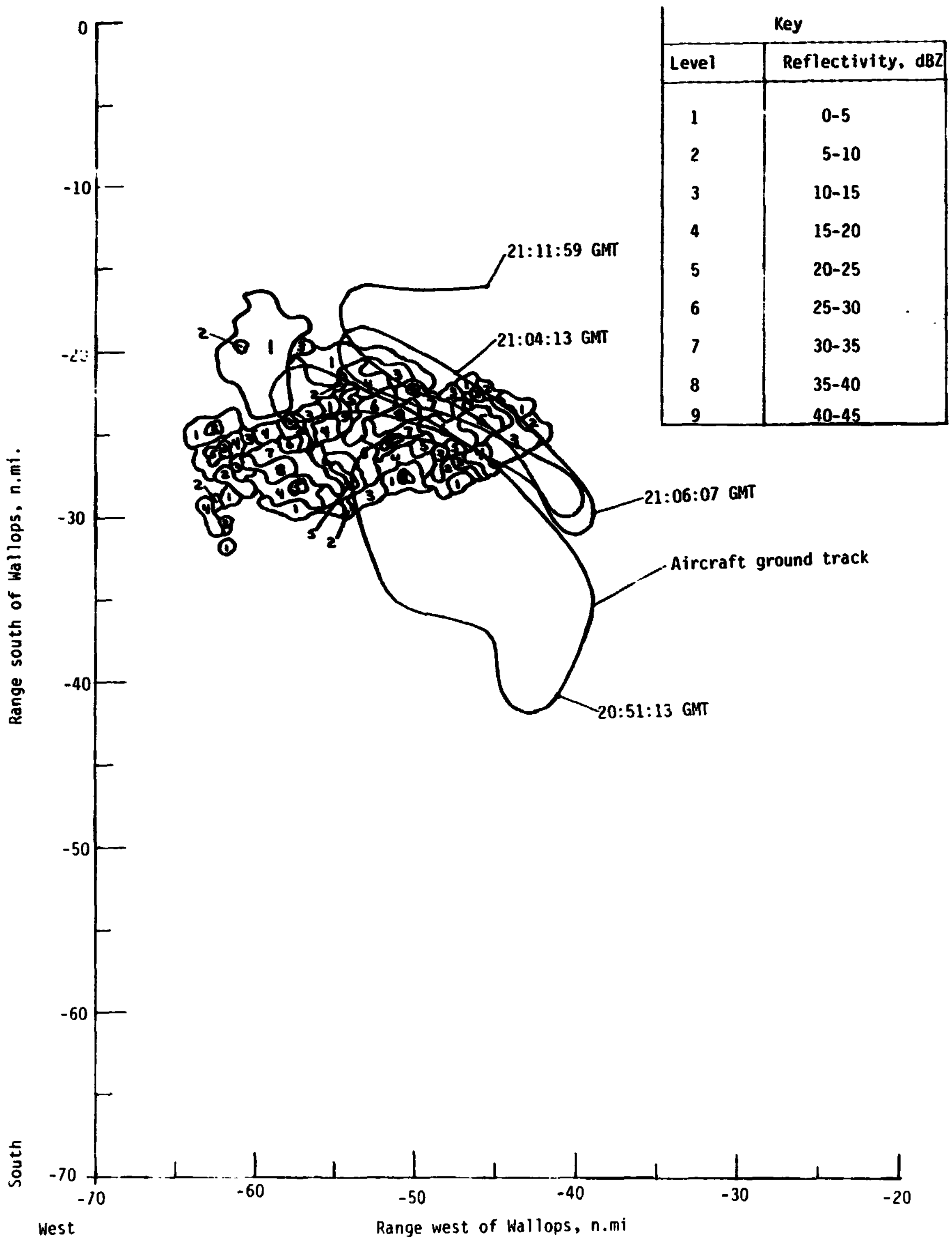


Figure ii.- SPANDAP reflectivity levels at 21:13:10 GMT and aircraft ground track from C-band radar for Yorktown storm (August 28, 1979).

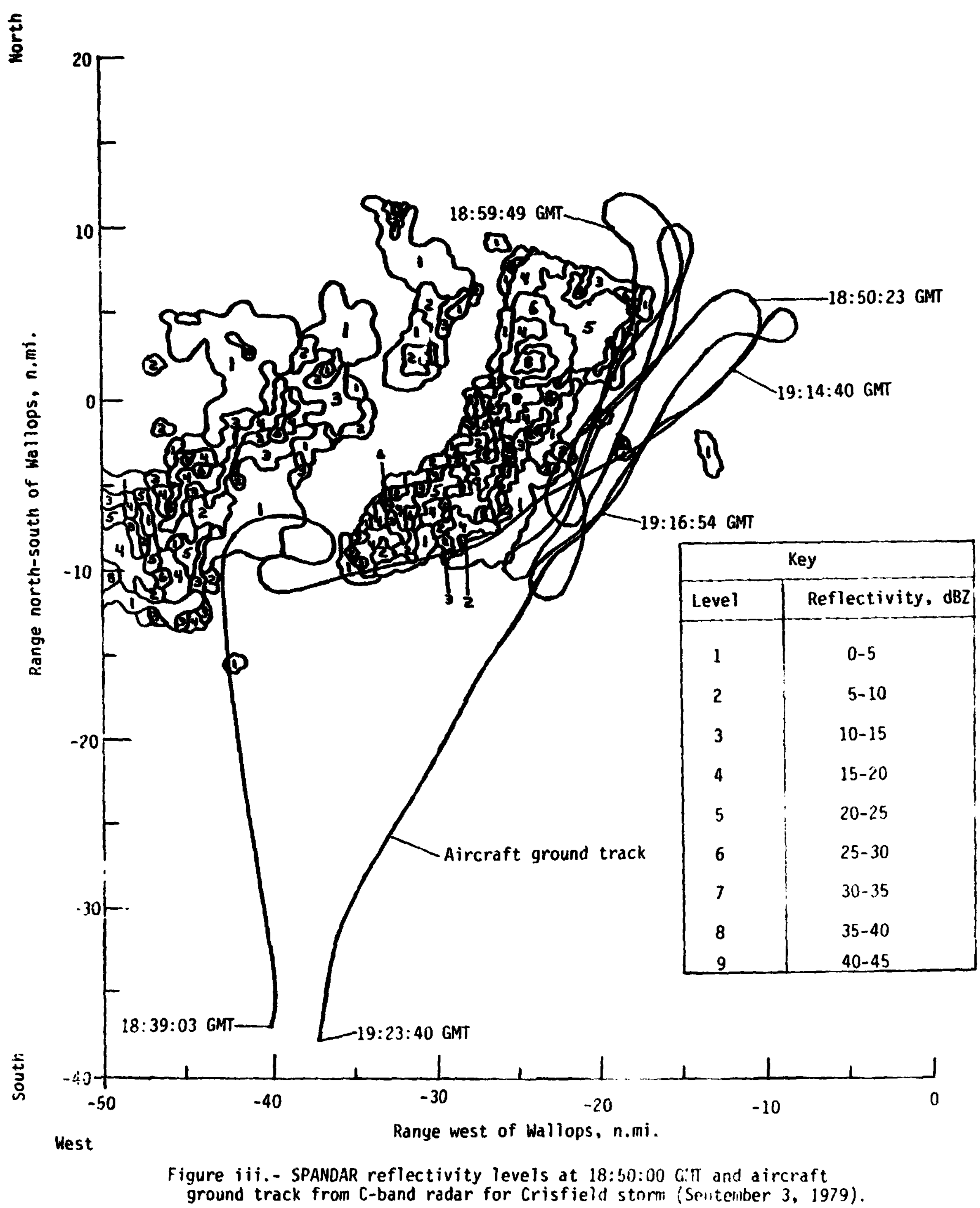


Figure iii.- SPANDAR reflectivity levels at 18:50:00 GMT and aircraft ground track from C-band radar for Crisfield storm (September 3, 1979).